THOMASON

CIVIL ENGINEERING COLLEGE MANUALS,

(Compiled by the College Staff.)

No. XIV.

SURVEYING.

(PART I.)

ORIGINALLY COMPILED BY

Lt.-Col. F. FIREBRACE, R.E.

REWRITTEN AND REVISED

BY

C. J. VEALE, Esq.,

Professor of Surveying and Drawing

ELEVENTH EDITION.

ALLAHABAD:

PRINTED BY W. C. A[illegible], [illegible] GOVERNMENT PRESS

On sale at the Book [illegible] Roorkee.

ERRATA.

SURVEY MANUAL, Part I.

Page 14, Fig. 12, is upside-down.
Page 70, line 3, *for* "shwon," *read* "shown."
Page 71, foot-note, *for* "erads," *read* "reads."
Page 79, line 21, *for* "51" *read* "50."
Page 80, line 8, *for* "51," *read* "50."
Plate facing page 85, *for* "Fig. 83," *read* "Fig. 33."
Page 100, line 2, *for* "para. 96," *read* "para. 86."
Page 106, line 13, *for* "6·650," *read* "6·605."
Page 106, lines 36 and 37, *for* both the 1st "S_1", *read*
Page 111, line 18, the full stop after "instru," *should be*
Page 112, line 19, *for* "accurancy," *read* "accuracy."
Page 155, line 34, *for* "decrease," *read* "decreases."
Page 157, line 13, *for* "thet ally," *read* "the tally."
Page 159, line 25, *for* "unweildy," *read* "unwieldy."
Page 164, line 13, *delete* "4·22—."
Page 165, line 2, *for* "must considered," *read* "must
Page 168, Plate XI., *for* "1·14" in + Diff. column,
Page 170, the 1st letter "1" *should be put in.*
Page 170, line 19, *for* "6·96," *read* "6·94."
Page 177, line 23, *for* "1·5740," *read* "$\bar{1}$·5740."
Page 180, line 38, first word *should be* "fixed."
Page 187, line 13, *should read* "interpolation, is suf
Page 191, line 17, *for* "unweildy," *read* "unwiel
Page 213, line 9, *for* "45·8," *read* "286·5."
Page 222, line 36, *for* "PCN," *read* "PCV."
Page 223, foot-note, *for* "$\left(1 + \frac{c}{10}\right)$" *read* "$\left(1 + \right.$
Page 229, line 11, *for* "$V = C^2$" *read* "$V = \frac{C}{8}$
Page 231, lines 6 and 7, *delete* the decimal points.
Page 235, line 17, *for* "Fig. 97," *read* "Fig. 98
Page 238, 2nd last line, *for* "$\sqrt{d\,(4r - d)}$," *read*
Page 240, line 33, *for* "1000 or 2000" *read* "10
Page 287, line 37, *for* "DB," *read* "Db."
Appendix, page 39, line 1, *for* "Plate XXII.,"

PREFACE TO THE ROORKEE TREATISE ON CIVIL ENGINEERING IN INDIA.

THE Roorkee Treatise was originally compiled by Lieut.-Col. J. G. Medley, R.E., in 1866 and issued in two volumes.

The Treatise grew out of the various College Manuals, dealing for the most part with subjects which required special treatment to suit the climate and methods used in India, and has been constantly revised and re-written. It is found advisable now to publish the Treatise in separate Sections, so that each Section can be re-written or revised and brought up to date whenever opportunity occurs, to keep pace with modern methods and discoveries.

The Treatise now contains the following Sections :—

Section	I.	Building Materials ...	Under revision.
,,	II.	Masonry ...	Under revision.
,,	III.	Carpentry ...	1904.
,,	IV.	Earthwork ...	Under revision.
,,	V.	Estimating ...	1915.
,,	VI.	Buildings ...	Under revision.
,,	VII.	Bridges ...	Ditto.
,,	VIII.	Roads ...	Ditto.
,,	IX.	Railways ...	Ditto.
,,	X.	Irrigation Works ...	Ditto.
,,	XI.	Sanitary Engineering ...	Ditto.
,,	XII.	Water-Supply ...	Ditto.
,,	XIII.	Drawing { Part I. / ,, II. ...	1915.
,,	XIV.	Surveying { Part I. / ,, II. ...	1915.

January 1915.

E. H. deV. A.

CONTENTS.

CHAPTER I.

GEOMETRICAL DRAWING.

MANAGEMENT OF PAPER, INSTRUMENTS, ETC., USED IN PLAIN DRAWING.

1. However well a survey may have been done in the field, it will never appear to its fullest advantage on paper, if great care and attention to minutiæ are not bestowed on its delineation. All surveys are essentially composed of details, and the greater the accuracy of the detail the more valuable the survey. Moreover, as all methods of surveying are based upon geometrical principles, geometrical drawing must play an important part in representing those details. A few hints, therefore, on the management of the instruments, &c., in most common use, will not be out of place here.

2. **Drawing Paper.**—The paper, of good quality but not too highly glazed, should present as smooth a surface as possible. Anything that tends to destroy the surface, such as erasures, excessive rubbing with india-rubber, washing, &c., should be avoided as much as possible. If india-rubber is necessary, it should be used sparingly, and pressed very lightly on the paper. Bread should be used instead of india-rubber when possible.

For survey work, or any work requiring accuracy, the paper should never be *wetted*, but damped only when stretched or mounted on a drawing board, on account of the distortion that takes place when the stretched paper is cut off. Unequal expansion or contraction should above all things be guarded against.

If the paper is buckled and requires flattening, the following method should be employed:—Mount the paper as described in the following paragraph. When nearly dry, cut it off the board, and place the sheets flat in a drawer, where they must be allowed to remain for three weeks at least, till they are thoroughly seasoned.

During the time occupied in plotting an extensive survey, the paper which receives the work is affected by the changes which take place in the hygrometrical state of the air, and the parts laid down from the same scale, at different times, will not exactly correspond, unless this scale has been first laid down upon the paper itself and all the dimensions have been taken from the scale so laid down.

For plotting an extensive survey, and accurately filling in the minutiæ a diagonal or vernier scale may advantageously be laid down upon the paper upon which the drawing is to be made. A vernier scale is preferable to a diagonal scale, because in the latter it is extremely difficult to draw the diagonals with accuracy, and there is no check on its errors; while in the former the uniform manner in which the strokes of one scale separate from those of the other is some evidence of the truth of both. The construction of scales will be treated of further on.

Drawing paper, properly so called, is made to certain standard sizes, as follows:—

Demy	... ...	20 inches	by	15½ inches.
Medium	... ...	22¾	„	17½ „
Royal	... ...	24	„	19¼ „
Super-Royal	... ...	27¼	„	19¼ „
Imperial	... ...	30	„	22 „
Elephant	... ...	28	„	23 „
Columbier	... ...	35	„	23½ „
Atlas	... ...	34	„	26 „
Double Elephant	... ...	40	„	27 „
Antiquarian	... ...	53	„	31 „
Emperor	... ...	68	„	41 „

Of these, Double Elephant and Imperial are the most generally useful sizes. Whatman's cold pressed paper is the quality most usually employed for finished drawings. For ordinary sketching or working drawings, cartridge paper may be used. It bears the use of india-rubber well, receives ink on the original undamped surface freely, shows a good line, but it does not take colours or tints very well. Cartridge paper can be obtained in any length up to 200 yards and in width 53 or 60 inches, and consequently is useful in certain cases. For delicate small-scale line-drawing, the thick blue paper imperial size, such as is made for ledgers, &c., answers exceedingly well.

Tracing paper is a preparation of tissue paper, rendered transparent and qualified to receive ink lines and tinting without spreading. When placed over a drawing already executed, the drawing is distinctly visible through the paper and may be copied or *traced* directly in Indian ink: thus an accurate copy may be made with expedition. Tracings may be folded and stowed away very conveniently; but, if likely to be frequently used, they should be mounted on cloth, or on paper and cloth, with paste.

Tracing paper may be prepared from Double-crown tissue paper by lightly and evenly sponging over one surface with a mixture of one part of raw linseed-oil or nut oil, and five parts of turpentine. Five gills of turpentine, and one of oil, will go over from $1\frac{1}{2}$ to 2 quires of twenty-four sheets.

Tracing cloth is a similar preparation of linen, and has the advantage of toughness and durability.

In colouring drawings on tracing paper or tracing cloth, the colour must be laid on the reverse side of the paper to that on which the lines are drawn.

The colour laid on should be much darker than the tint required in the drawing.

3. **Mounting Drawing paper on Drawing boards.**—The edges of the paper should be first cut straight, and as near as possible at right angles with each other; also the sheet should be so much larger than the intended drawing and its margin, as to admit of being afterwards cut from the board.

The paper must be first thoroughly and equally damped with a sponge and clean water, *on the opposite side from that on which the drawing is to be made.* When the paper absorbs the water, which may be seen by the wetted side becoming dim, as its surface is viewed slantwise against the light, it is to be laid on the drawing board with the wetted side downwards, and placed so that its edges may be nearly parallel with those of the board: otherwise in using a T-square inconvenience may be experienced (see also Chapter VII).

This done, lay a straight flat ruler on the paper with its edge parallel to, and about half an inch from, one of its edges. The ruler must now be held firmly while the projecting half inch of paper is turned up along its edge; then a brush containing strong paste must be passed once or twice along the turned up edge, after which by sliding the ruler over the pasted border the paper will again be laid flat, and the ruler being pressed down upon it, that edge of the paper will adhere to the board. In exactly the same manner fix down an *adjoining* edge, after which paste the longer of the two remaining sides and finally the shorter side. If the opposite and parallel sides of the paper are pasted first, a much greater degree of care is required to prevent undulations appearing as the paper dries, and even then success is not always certain. The mounted paper should be allowed to dry gradually, and the process should not be hastened by putting it before a fire or in the strong sunshine, otherwise the unpasted portion,

which dries more quickly than the pasted portion, is very apt to tear itself away from the pasted border. A small quantity of alum is a very good thing to mix with the paste, for it not only enhances the adhesive properties of the paste, but the drawing, when dry, is not so stiff as if paste only is used.

Mounting Drawing paper on Canvas or Linen.—Large sheets, destined for rough usage and frequent reference, should be mounted on linen or canvas. The latter should be well stretched upon a smooth flat surface, such as a drawing board or table, and its edges pasted down as recommended in stretching drawing paper. The flat surface on which the canvas is stretched must either be well varnished or well greased (all superfluous grease being removed), for if this is not done, the subsequent operations will cause the canvas to stick to the surface. The canvas being stretched, strong paste is to be spread upon it with a brush (this is not necessary if fine linen be used), and is to be beaten in till the grain of the canvas is all filled up; this, when dry, will prevent the canvas from shrinking when subsequently removed. Having cut the edges of the paper straight, paste one side of every sheet and lay them upon the canvas sheet by sheet, overlapping each other a small quantity. If the drawing paper is strong it is better to let every sheet lie for some five minutes after the paste is put on it; for as the paste soaks in, the paper will stretch, and may be better spread smoothly on the canvas, whereas if it be laid on before the paste has moistened the paper, it will stretch afterwards and rise in blisters when laid upon the canvas. When the paste has soaked in, it is as well therefore to go again over the paper with the paste brush containing very little paste; this is done to moisten the whole surface again and to take off any lumps or superfluous paste; it should then be placed on the canvas as gently as possible, and the centre be pressed down on to the canvas by means of a cloth or something soft; from that work outwards towards the edges, the lines of pressure exerted always tending from the centre. Air bubbles between the canvas and paper may be got rid of by puncturing the spot with a fine needle and then pressing it down with a handkerchief. The paper should not be cut off until thoroughly dry, neither should the drying be hastened, but allowed to take place in a dry room.

4. The **pencil,** either an H, or an HH, should have a moderately fine point and when being used should be [illegible] pressed upon the paper, and slightly inclined in the direction in which the line is being drawn, care being taken to keep it, throughout the operation, in the same position with reference to the ruler.

The worker in the field will find that a 6 H will be none too hard in the hot weather after a few days work, certainly a 2 H would be too soft. A pencil point protector is a cheap and useful article to have. The lead can be best kept sharp on a small smooth file, or a piece of fine glass paper.

4. **(a) Indian Ink.**—If a stick of ink is used, it should be carefully rubbed up with water, a drop or two to start with gradually increasing the quantity; it should be free from grit and above all, not too thick. One or two trials (by drawing two or three lines on a piece of waste paper) while the ink is being prepared, will ensure a proper consistency. Great care should be taken to see that it is worked up sufficiently to ensure a thoroughly black line. Ink should be made fresh daily. Indian ink when stale gives brown lines and is not water proof. Liquid Indian ink, of excellent quality, however, can now be obtained and is in many ways more convenient to use than stick Indian ink.

5. **Instruments.**—A case of instruments generally contains:—

(*a*) Compasses with movable parts—(1) Plain Point; (2) Pencil Point; (3) Ink Point; (4) Lengthening Bar.
(*b*) Ink Bow Compass.
(*c*) Pencil Bow Compass.
(*d*) A set of Spring Bows—(1) Dividers; (2) Pen*; (3) Pencil.*
(*e*) Drawing Pens.
(*f*) Plain Dividers.
(*g*) Parallel Ruler.
(*h*) Pricker.
(*i*) Protractor.
(*j*) Marquois' Scales.
(*k*) Sector.
(*l*) Proportional Compass.
(*m*) Curves.

Cheap cases do not contain all these instruments, while some draftsmen use many other varieties. Other useful instruments are:—

(1) Set squares. | (2) T-Square.
(3) A Beam Compass.

(*a*) **Compasses** should be held at the top between the forefinger and thumb, with one or more fingers under the hinge to increase or diminish the distance between the points gradually and without a jerk; in all cases the steel point should be guided by the finger of the other hand to the centre of the circle to be drawn, or to the line or scale to be measured. When several concentric circles are to be drawn, great care is requisite to avoid enlarging the centre. Persons unaccustomed to the use of compasses are very apt to turn them over and over in the same direction

* The pump bow ink and pencil for making circles is far superior to the type sold in instrument boxes.

when spacing off a number of equal distances the divisions of a scale. This necessitates a constant change of the hold by means of the finger and thumb, which often causes the point of compass to be forced into the paper, or to be jerked off the point fixed altogether. To obviate this, the points of the dividers should be worked alternately above and below the line along which the divisions are being set off, by this means the manipulation will be much more delicate, and there will be no liablity of the compasses shifting.

(*b*) **The Drawing or Line Pen.**—In using a pen, dip it into the ink and wipe the outside of the points clean with a rag. The pen is now ready for use. Hold the pen lightly against the ruler, taking care that it is vertical as the points have been ground by the maker so as to give the best lines when used *vertically*; be very careful to make both nibs touch the paper, to preserve an even pressure and the same position of the pen with regard to the paper and ruler throughout with a *slow* but equal motion along the ruler. The pen should not be tested for ruling on the hand which is greasy but on a sheet of stiff paper. By attending to these points, the pen will mark throughout the whole length of the line, an equal thickness of line being secured, and rugged edges avoided. If after working some time it is found that the ink does not run freely from the pen, it may be amended by passing a small slip of paper (not blotting) between the nibs. Above all things the paper must be kept clean: it should not be touched by the hands more than possible, as the hand makes the paper greasy; and when once the paper has acquired this defect, clean sharp lines are impossible. In inking in over pencil lines, work from the top of the paper towards the bottom; this will prevent any risk of smearing. The pen should be carefully cleaned and dried before being laid aside.

A drawing pen should have its nib ends exactly uniform in length and width and the points should be as thin as it is possible to set them. A hone is all that needed to set the points of the nibs.

(*c*) **Parallel Rulers.**—These are of two kinds :—

(1) *The plain parallel ruler.* This should be tested to see that the distances between the pivots on the rulers and the lengths of the bars are exactly equal in each case.

(2) *The rolling parallel rule*. This should be heavy enough to ensure stability. It can be tested by running it in one direction and ruling two parallel lines and then reversing the run and noting the error, if any, between the lines drawn at the end of each run. For accurate work it is best to avoid all parallel rulers and to use Marquois' scales.

(*d*) **Protractor.**—The most general use of the protractor is for setting **off upon paper any given angle. A variety of scales are, however, drawn on both sides of the instrument which are extremely convenient.**

The following is a detailed description of the method of using the protractor :—

The *protractor* is generally a rectangular piece of ivory or boxwood 6 inches long by 1¾ inches to 3 inches broad. Round three of its edges the angles are marked (the lines radiating from a point in the centre of the fourth side) and should be numbered in two rows, the outside from 0° to 180°, and the inside from 180° to 360°. The method of using it to set off any required angle is easily seen by an example.

Suppose we wish to draw from the point C in the line CA another line making an angle of 40° with CA [*Fig.* 1, *Plate* I.] Place at C the centre mark on the lower edge of the protactor, and keeping it there, move the protractor round till the line numbered 40°, on the radiated edge, coincides with CA. Draw the line CD along the edge; DCA is the required angle, which has thus been simply transferred from the scale to the paper. When the line CA is not long enough to admit of the above construction, it will be necessary to place the lower edge of the protractor on that line, with the centre on C [*Fig.* 2, *Plate* I.], then to make a mark against the upper edge at the line indicating the required angle, and removing the protractor, draw a line through the two points.

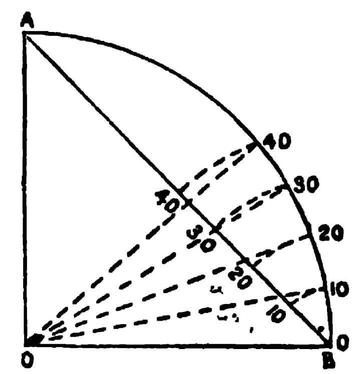
Protractors are usually of two patterns—The draftsman's pattern and the military pattern. The draftsman's pattern contains a variety of scales on both sides—they are simple scales. Those marked 30, 35, 40, 45, 50, 60, being the same as those on the Marquois' scale described further on (page 9). These numbers simply representing the number of parts into which the inch is divided. i.e., on the 30 scale, thirtieths of an inch can be taken off; on the 40 scale, fortieths of an inch, and so on. The use of these scales is found when we have to employ for a drawing a scale such that one of these divisions represents a convenient unit of measurement, such as 1 foot, 1 yard, 10 feet, 10 yards, &c., &c.

The scales marked In. ⅞, ⅝ &c., &c., are also simple proportional scales. The numbers ⅞, ⅝, &c., refer to the length of one division, which is divided into 12 parts. That marked In. being one inch long, that marked, ⅞, ⅞th of an inch long, and so on. These scales are useful for measurements involving feet and inches on account of the duodecimal minor divisions. They are not generally so convenient, however as the other scales just described. The diagonal scale is an ordinary one. The inch being divided into 10 parts 1/100th of an inch being obtained by means of the diagonal

lines; where the ½ inch is divided into 10 parts, we can, of course, obtain *1/200th* of an inch. The principle of this and the method of construction will be explained further on.

The scale marked Cho., is a scale of chords, and deserves attention. It is constructed in this manner:—Take a quadrant AOB, *Fig.* 3, divide the arc into arcs of 10°, and number these 10, 20, 30, up to 90, from B to A. Join AB, and with B as centre and radii from B to these various divisions describe arcs cutting AB, in the points 10, 20, 30, &c. These various radii are the chords of the different arcs; consequently AB is called a scale of chords. Each scale will vary with the length of the radius; but Euclid, IV 15, proves that the side of a hexagon is equal to the radius of the circumscribing circle; or in other words, the radius of the circle = the chord of 60°.

Fig. 3.



To use the scale.—With centre C [*Fig.* 4, *Plate* I.], and radius equal to the distance from zero to 60° on the scale [*Fig.* 1, *Plate* I.] describe an arc HK, cutting CA in H, and with centre H, and radius equal to the distance from zero to 40°, or other given angle, describe an arc intersecting HK in K, join CK; KCH is the required angle.

This method of protracting angles is much to be preferred to simply laying them off by the protractor, as it is more accurate, and the greater the radius the greater the accuracy.

The military pattern protractor generally differs from the above in having none of the above scales marked except the diagonal scale. As it is usually used for surveying purposes, in place of the scales described above, scales of one, two, four, six and eight inches to the mile are given, together with a normal scale of horizontal equivalents. The protractor can also be used as a clinometer, by boring a small hole near the edge of the protractor and suspending a small weight by a thread.

(*e*) **Marquois' Scales.**—The box of *Marquois' Scales* contains two rectangular rulers and a right-angled triangle, of which the hypotenuse or longest side is three times the length of the shortest. Each ruler is a foot long, and has parallel to each of its edges, two scales, one placed close to the edge, and the other immediately within this, the outer being termed the artificial and the inner the natural scale. The divisions upon the outer scales are three times the length of those upon the inner scale, so as to bear the same proportion to each other that the longer side of the

triangle bears to the shorter. Each inner, or *natural scale, is in fact, a* simply divided scale of equal parts having the primary divisions numbered from the left hand throughtout the whole extent of the rule. In the artificial scales the zero point is placed in the middle of the edge of the rule and the primary divisions are numbered both ways, from the centre point outwards. Each division on this scale is three times the length of a corresponding division on the natural scale. The triangle has a short line drawn perpendicular to the hypotenuse, near the middle of it, to serve as an index or pointer; and the longer of the two sides has a beveled edge.

The rectangular rulers have numbers 25, 30, 35, 40, 45, 50, 55, 60 marked on each scale: these numbers simply show how many divisions the inch is divided into on the natural scale; the artificial divisions being three times the natural division. We are enabled by the method shown below to draw parallel lines from $\frac{1}{25}$th to $\frac{1}{60}$th of an inch apart, or any multiples of these fractions. Instrument makers usually number the rulers and triangle and these should be examined to see that they correspond and belong to one set.

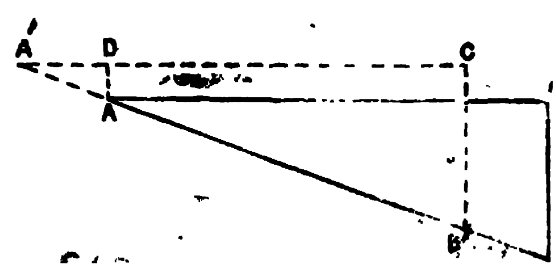
(f) **To draw a line parallel to a given line at a given distance from it.**

(1) Having applied the given distance to one of the natural scales, which is found to measure it most conveniently, place the triangle with its sloped edge coincident with the given line, or rather at such a small distance from it, that the pen or pencil passes directly over it when drawn along this edge. (2) Set the ruler closely against the hypotenuse, making the zero point of the corresponding artificial scale coincide with the index upon the triangle. (3) Move the triangle along the ruler, to the left or right, according as the required line is to be above or below the given line, until the index coincides with the division or sub-division corresponding to the number of divisions or sub-divisions of the natural scale, which measures the given distance, and the line drawn along the sloped edge in its new position will be the line required.

The proof of this is as follows:—If ABC, *Fig.* 5, represent the triangle in its new position, and the dotted lines represent its original position, by similar triangles ABC, AA'D,

AD : AA'=BC : BA=1 : 3 and therefore AD contains as many divisions of the natural as AA' contains of the artificial scale.

Fig 5.



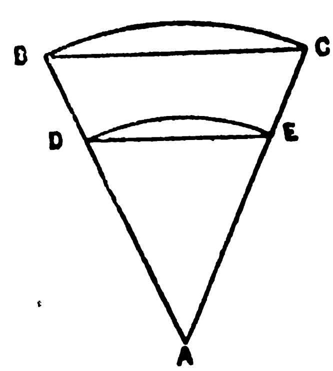
(*g*) **Sector.**—The Sector is a ruler 12 inches long and about half an inch broad, jointed in the centre so as to allow of its being folded together, in the direction of its depth. A sector either of wood or ivory is generally supplied with ordinary instrument boxes. A more detailed description of its construction is therefore necessary.

The most important scales and the ones which are really of most service in geometrical construction are the line of lines, the line of chords and the line of polygons.

Line of Lines.—The principle of the use of the line of lines is as follows:—Let the lines AB, AC, represent a pair of sectoral lines, and BC, DE any transverse distances taken on this pair of lines; then, from the construction of the instrument AB=AC and AD=AE, so that

AB : AC=AD : AE

Fig 6



and the triangles ABC, ADE have the angle at A common, and the sides about the equal angle proportional (Euc. VI., 6); they are, therefore, similar.

and AB : BC=AD : DE.

From the above, the use of the *line of lines* is self-evident. For example:—

To divide a line 3·11 inches long into 7 equal parts. Take the length of the line into the compasses, and having set one point in the division which is numbered 7, open the instrument till the other point of the compasses meets the 7th division on the other limb, then the distance between the two points marked 1, will obviously be the $\frac{1}{7}$th part of the line as required, or equal to ·44 of an inch nearly; but it must be observed, that owing to the inevitable imperfection and wear of all instruments, this distance must be stepped along the line to ascertain whether it may not require a small correction.

Example 1.—To determine $\frac{2}{7}$ths of a line 3 inches long; take that length in the compasses and open the sector until it coincides with the primary divisions 7, 7, when the distance between 2 and 2, is that required.

Example 2.—To find $\frac{9}{23}$rds of a line 4·09 inches long [*Fig.* 7, *Plate* I.]

Since there are only ten primary divisions, recourse must be had to the secondary divisions, to solve this problem. In order to bring the construction some distance from the centre, which will insure the accuracy of the result, multiply the numerator and denominator of the fraction by some number which will make the denominator when so multiplied near, but not greater than 100: in this case 4 is a convenient multiplier; then

$\frac{9}{32}=\frac{36}{92}$ having taken off 4·09 inches in the compasses, make that length a transverse distance at the secondary division 92, then the transverse distance at 36 will give the part required.

Note.—A *lateral distance* is a distance measured from the centre along any sectoral line. A *transverse distance* is a distance measured from a point in one line of a pair of sectoral lines to the corresponding point in the other line.

(*h*) *Line of Chords.*—This scale is similar to the one marked Cho. on the protractor, and is used for the same purpose; but the double scales of chords on the sector are generally more useful than the single scale on the protractor; for on the sector, the radius with which the arc is to be described may be of any length between the transverse distance of 60 and 60 when the legs are closed, and that of the transverse of 60 and 60 when the legs are opened as far as the instrument will admit of; but with the scale on the protractor, the arc described must always be of the same radius.

To lay down an angle which shall contain a given number of degrees:—

1. When the angle is less than 60°; say 46°.

Make the transverse distance of 60 and 60 equal to the length of the radius of the circle, and with that opening describe the arc BC [*Fig.* 8, *Plate* I]. Take the transverse distance of the given degrees 46°, and lay this distance on the arc from the point B to C. Join AC, AB; the angle CAB is the one required.

2. When the angle contains more than 60°; say 148°.

Describe the arc BCD, making the radius equal to the transverse distance of 60 and 60, as before. Take the transverse distance of $\frac{1}{2}$ or $\frac{1}{3}$, &c., of the given number of degrees, and lay this distance on the arc twice or thrice, as from B to *a*, *a* to *b* and *b* to D. Join BA, AD; BAD is the angle required.

3. When the required angle contains less than 5°, suppose $3\frac{1}{2}$°, it will be better to proceed thus:—With the given radius, and from the centre A, describe the arc DG; and from some point D lay off the chord of 60°, thus giving the point G such that the angle DAG=60°. From the same point D lay off in the same direction the chord of $56\frac{1}{2}$° (=60°−$3\frac{1}{2}$°), thus giving the point E such that the angle DEA=$56\frac{1}{2}$°. Then the angle GAE is the angle required.

(*i*) **Line of Polygons.**—*The line of polygons* is chiefly useful for the ready division of the circumference of a circle into any number of equal parts from 4 to 12; it forms, therefore, a ready means of inscribing regular polygons in a circle. To do this, set off the radius of the given

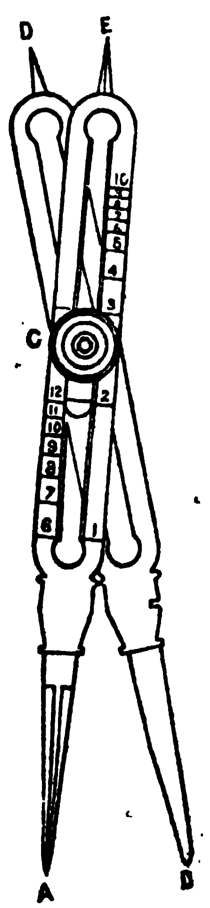
circle (which is always equal to the side of the inscribed hexagon) as the transverse distance of 6 and 6 upon the line of polygons. Then the transverse distance of 4 and 4 will be the side of the inscribed square; that of 5 and 5 the inscribed pentagon, that of 7 and 7 the inscribed heptagon and so on.

It is required to form a polygon upon a given right line, set off the extent of the given line as a transverse distance between the points upon the line of polygons, answering to the number of sides of which the polygon is to consist; as for a pentagon between 5 and 5, or an octagon between 8 and 8, then the transverse distance of 6 and 6 will be the radius of the circle which is to be described so as to contain the given line; if now we set off the length of this line round the circumference of the circle we shall obtain a regular polygon of the required number of sides.

(*j*) **Proportional Compasses.**—These, though of great service in many problems which occur in plan drawing, are not supplied with the ordinary instrument boxes. A description of the method of using them is, however, considered necessary.

They consist of two equal and similarly formed parts or limbs AE and BD (*see Fig.* 9), opening upon a centre C. and forming a double pair of compasses whose points are A, B, E, D. When shut up, the two limbs appear as one, and a small stud fixed in one fits into a notch made in the other, and retains the instrument in its closed position. The adjustment of the instrument must be made when both limbs coincide; as it is only in this position that the centre piece C can be moved up and down. The chief use of the proportional compasses is to reduce a drawing in any given proportion. To do this the centre C is shifted up or down as required, thereby shortening one set of legs and lengthening the other. The distance to be reduced is measured off with one set of legs, and the distance shown by the other pair will be the corresponding length, reduced or increased from the original length in a ratio depending upon the position of the centre C. As in the sector, various other geometrical constructions can be performed by means of the different scales given on either side of the limbs; it will be sufficient, however, to describe the method of adjusting the instrument for laying off distances on a plan, the scale of which is to bear a certain proportion to that of a given plan.

Fig. 9.

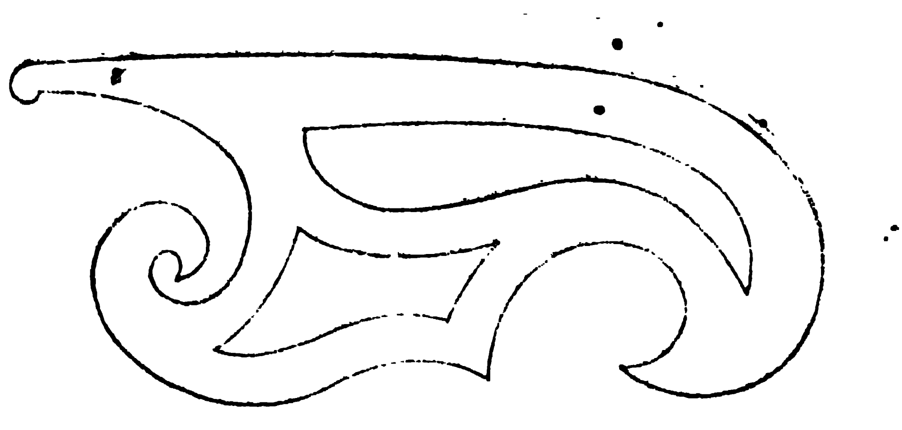


On the face of each limb there are four sets of divisions, one denominated "Lines," a second "Circles," a third "Planes," and the fourth "Solids." It is with the first of these, viz., the Line of Lines, that we have to do.

When the zero of the centre on the dove-tailed sliding piece is set to the division marked 1 on the line of lines, and clamped by turning the mill-headed screw C, any opening of the compasses will give equal distances at both extremities. When the zero is in a similar manner set to 2 on the line of lines, the proportions between the openings of the points A, B, the corresponding openings of the points D, E, will be as 2 to 1, in other words, any distance set off by D, E, will be half the distance measured by A, B. Similarly if the zero be set to 3, the distance set off will be to the distances measured as 1 to 3, and so on for the other divisions which extend up to 10.

(*k*) **Curves.**—For curves which are not circular, but variously elliptic or otherwise, "French" curves made of thin wood, of variable curvature, are very serviceable. The two examples (*Figs.* 10 and 11) have been found from experience to meet almost all the requirements of ordinary drawing practice. Whatever be the nature of the curve, some portion of one of these "French" curves will be found to coincide with its commencement, and other portions can be used to complete the curve.

Fig. 10.



"French" Curve—One-fourth full size.

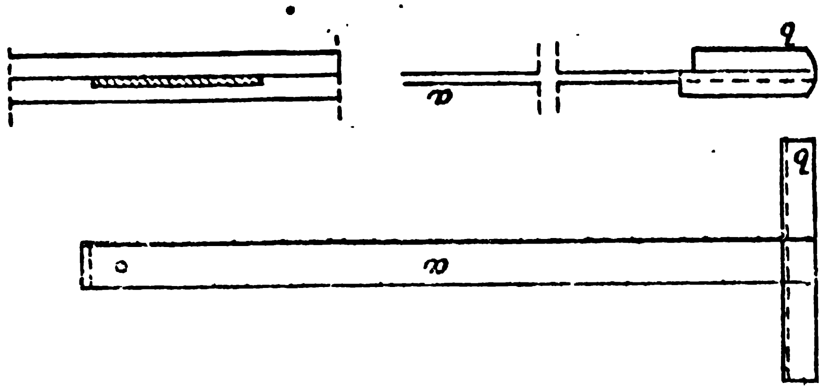
(*l*) **Set-Squares.**—A few set-squares of various sizes are useful. They consist of triangular pieces of wood, celluloid or vulcanite. One angle is invariably a right angle, and the other angles may be 45, 30 and 60 degrees. Set-squares are used in conjunction with a straight-edge for drawing lines at right angles to each other, or for drawing parallel lines.

Fig. 11.

"French" Curve—One-fourth full

(*m*) **T-Square.**—The T-Square (*Fig.* 12) is a blade or "straight-edge" *a*, usually of mahogany, fitted at one end with a stock *b*, applied transversely at right angles. The stock being so formed as to fit and slide against one edge of the board, the blade reaches over the surface, and presents an edge of its own at right angles to that of the board, by which parallel straight lines may be drawn upon the paper. To suit a 41-inch board, the blade should measure 40 inches long clear of the stock, or one

Fig. 12.



Details of T-Square

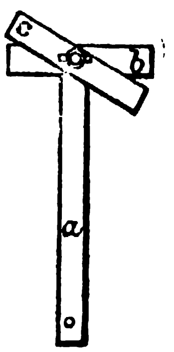
inch shorter than the board, to remove risk of injury by overhanging at the end: it should be $2\frac{1}{2}$ inches broad by $\frac{3}{32}$ inch thick, as this section makes it sufficiently stiff laterally and vertically. If thinner, the blade is too slight and too easily damaged by falls and other accidents, and is liable to warp; if thicker, it is too heavy and cumbersome; if broader, it is heavier without being stiffer. The tip of the blade may be secured from splitting by binding it with a thin strip inserted in a saw-cut as shown. The stock should be 14 inches long, to give sufficient bearing on the edge of the board, 2 inches broad, and $\frac{5}{8}$ inch thick, in two equal thicknesses glued together. With a blade and stock of these sizes, a well-proportioned T-square may be made, and the stock will be heavy enough to act as a balance to the blade, and to relieve the operation of handling the square. The blade should be sunk flush into the upper half of the stock on the inside and very exactly fitted. It should be inserted full breadth, as shown in the figure; notching and dove-tailing is a mistake, as it weakens the blade and adds nothing to the security. The lower half of the stock should be only $1\frac{3}{4}$ inches broad, to leave a $\frac{1}{4}$ inch check or lap, by which the upper half rests firmly on the board, and secures the blade lying flatly on the paper.

One-half of the stock *c* (*Fig.* 13) is in some cases made loose, to turn upon a brass pin to any angle with the blade *a* and to be clenched by a screwed nut and washer. The turning stock is useful for drawing parallel

lines obliquely to the edges of the board. In most cases, however the sector, and the other appendages above described, answer the purpose, and do so more conveniently. A square of this sort should be rather as an addition to the fixed square, and used only when the level edge is required, as it is not so handy as the other.

The edges of the blade should be very slightly rounded, as the pen will thereby work the more freely. It is a mistake to chamfer the edges—that is, to plane them down to a very thin edge, as is sometimes done, with the object of insuring the correct position of the lines; for the edge is easily damaged, and the pen is liable to catch or ride upon the edge, and to leave ink upon it.

Fig 13.



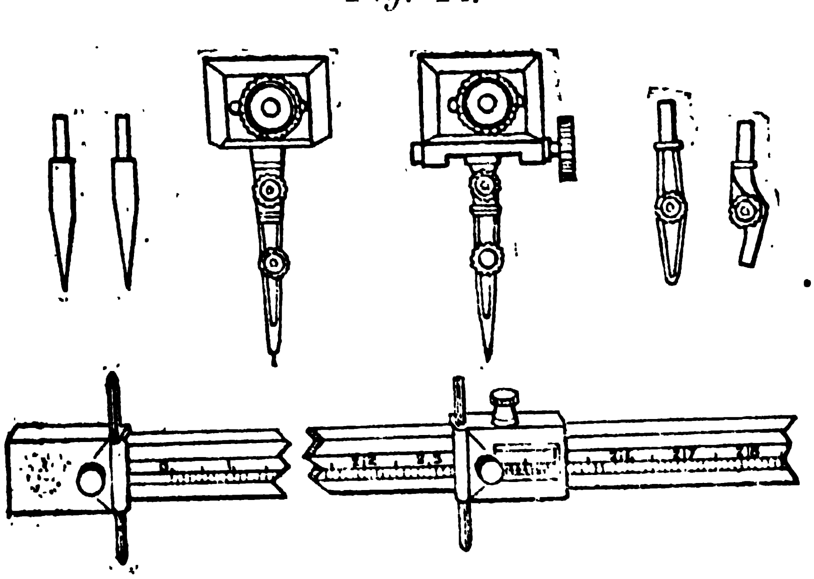
A small hole should be made in the blade near the end by which the square may be hung up out of the way when not in use.

No varnish of any description should be applied to the T-square, or indeed to any of the wood instruments employed in drawing. The best and brightest varnish will soil the paper. The natural surface of the wood, cleaned and polished occasionally with a dry cloth, is the best and cleanest for working with. The wood should be non-oily and well seasoned.

(*n*) **Beam Compasses.**—Beam compasses are used for setting off accurately distances which are beyond the stretch of an ordinary compass.

They consist of two beam heads moving on a graduated bar of wood or

Fig. 14.



electrum. Each beam head has a clamp to hold a pointer or pencil. of these heads is fixed at one end of the bar, and is provided with a vert screw for making fine adjustments, while the other is free to move up down on the bar and can be clamped in any position.

If a scale is given on the bar, it should never be used for accurate work, but distances should be taken direct from a scale drawn on the paper on which the plan has been plotted. Beam compasses are used to test the rectangular margins of a sheet, and the perpendicularity of the central meridian line of a survey to a parallel of latitude, by the usual method of checking a right angle, viz., measuring 3 and 4 (or their multiples) on the perpendiculars and testing the hypotenuse with the distance 5 or its multiple.

6. **Printing.**—It cannot be too strongly insisted upon that a finished drawing cannot be produced without first class printing Too much care cannot be given to this matter, as a good style of printing is essential to the production of a really good engineering or topographical drawing, more especially the latter, as the names of towns and villages are all over the place.

This perfection cannot be attained without a great deal of practice, care and perseverance. It must, however, be pointed out that this perfection should only be expected from, and sought after by, draftsmen and the subordinate ranks.

Engineers and superior officers should seldom waste their time in endeavouring to print up a drawing with fine headings and copper-plate printing. They should content themselves with producing neat and legible words and leave the finished work to their less highly educated inferiors.

This para, however, will be devoted to showing how any intelligent man, with care and perseverance, can become a first-rate printer.

(a) As a rule **Block Printing** is decidely the best for all kinds of headings, being neat and legible. For main headings fancy letters may occasionally be used, but it may be laid down as an axiom that the plainer the lettering on a drawing the better.

Block printing may be either upright or sloping. The proportion of breadth to height varies considerably in different alphabets, and may range from the "square" form in which the breadth is equal to the height, down to the "elongated," in which the breadth is reduced to anything down to one-third of the height.

The first thing to do is to decide the height of the letters it is proposed to use for a heading. This must entirely depend on the size of the drawing and should be strictly in proportion. Having decided the height, it is next necessary to decide the proportion of breadth to height.

The most symmetrical in appearance and the easiest to execute is an alphabet in which the breadth of the larger number of the letters is four-fifths of the height. Divide the height selected into five spaces (*Plate* II).

Then most of the letters are four of these spaces broad. The exceptions are—I = 1, J = 3, F L = $3\frac{1}{2}$, M T W = 5. The spaces between the letters may be 2 or $1\frac{1}{2}$, and between the words 5 or 6 according to taste.

Then to put in a heading, after selecting size, write it roughly thus—

P	L	A	N	A	N	D	S	E	C	T	I	O	N	
4	$3\frac{1}{2}$	4	4	4	4	4	4	4	4	5	1	4	4	spaces=$53\frac{1}{2}$
2	2	2	6	2	2	6	2	2	2	2	2	2		„ =34
														Total=$87\frac{1}{2}$

Take $87\frac{1}{2}$ spaces and place centrally. Then rule the boundary lines *of each letter* and *after, if necessary*, the single space lines within each letter. This gives as little ruling as possible and also gives spaces correct. If single space lines are ruled all along one letter of the $3\frac{1}{2}$ breadth throws out all those after it.

If a more upright narrower style is required, instead of taking spaces $\frac{1}{5}$th the height take them $\frac{1}{6}$th or $\frac{1}{7}$th.

It should be borne in mind that the terminations of all letters should be always flat, never pointed or rounded.

One of the difficulties of the beginner is to know what is bad and what is good printing, it will, therefore, be useful to point out a few of the mistakes to avoid, and points to be noted in the formation of certain letters. Refer for each letter to Plate II.

In the letter A, the cross stroke should be about one-third of the way from the bottom of the letter.

In the letter B, the upper portion should be about one-tenth smaller and not quite so broad as the lower portion.

In the letter C, take care that you place the lower termination exactly below the upper one.

In the letter E, the upper horizontal stroke should be slightly shorter than the lower one, but be careful to avoid exaggeration.

In the letter G, avoid all fancy forms.

In the letter K, the upper diagonal meets the perpendicular stroke two-thirds of the way down. The lower diagonal joins the upper one in such a position that if it were produced it would meet the perpendicular stroke one-third of the distance from the top.

The letter M requires to be treated with a certain amount of discreti if the strokes used are broad the letter should be five spaces broad to av looking heavy; if the strokes used are thin the letter should be only fo spaces broad.

In the letter R the lower termination of the tail should be flattened.

The letter S is a very difficult letter to form; the upper half should be less broad than the lower, and a horizontal line dividing the upper and lower curves should be nearer the top than the bottom. If the two curves are made the same the letter will look top-heavy as may be seen in the Plate.

The upper stroke of the letter Z should be somewhat shorter than the lower stroke.

(*b*) **Italic Printing** (Plate III), is well adapted for the information to be entered on ordinary plates and surveys. To execute this, the beginner should rule three lines parallel to each other to regulate the heights of the small letters and capitals. The distance apart of these lines will depend on the size of the printing desired, but lines three and four-sixtieths apart will be found convenient to start on. Parallel lines should then be ruled at intervals of about half an inch to define the slope of the printing.

The beginner should pencil each letter in with the greatest care before inking in, avoiding the use of india-rubber. When he has gained sufficient proficiency through practice, the pencil may be dispensed with. Students should remember that it is impossible to print after taking any violent exercise as the hand is not sufficiently steady.

In Plate IV, is given an example of another style of printing, which is fairly easy to acquire and which may be occasionally useful.

Plate IV A, is now the accepted rapid style in which drawings may be finished. Field notes and figuring in this style is recommended as it lends itself to any class of nibs and especially medium pointed fountain pens. The style is easily learnt and variations of it will be recognised in most recent plan drawings and survey maps.

General Rules applicable to all Geometrical Drawing.

1. Instruments, *especially ruling pens*, should be kept scrupulously clean. *Clean drawings* cannot be executed without *clean hands*. Keep a piece of paper under the hand when working. Wooden and ebonite rulers can be cleaned by rubbing them with bread. Always rub them on a piece of paper before commencing work.

2. Never draw a single line that is not absolutely necessary. Always work with a sharp point to your pencil. Do not cut it at the lettered end. Pencil work should be done as *lightly* as possible. If the lines are heavy they are difficult to rub out and soil the rulers.

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z.

a b c d e f g h i j k l m n o p q r s t u v w x y z

1 2 3 4 5 6 7 8 9 10 $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$

Buildings. Bridges. Plan. Elevation. Section. Scale.

Scantlings of Rafters. Purlin. Tie Beams. Strap.

Bolt 1" diameter. Flat Arch. Relieving Arch. Ground line.

Bressummer. Slope 1 in 20. Wall-Plate. Rafter.

Weather Boarding. Ridge Pole. Ventilator. King post truss.

Angle Iron. Sheet Iron. T Iron. Calcutta. Allahábád.

Roorkee. Kashmere. Indus. Ganges. To Morádábád.

fr. Bareilly

Italic printing is well adapted for the information to be entered on ordinary Plates and Surveys.

To execute this, the beginner should rule three lines parallel to each other to regulate the heights of the small letters and capitals. The distance apart of these lines will depend on the size of the printing desired, but lines three and four sixtieths apart will be found convenient to start on. Parallel lines should then be ruled at intervals of about half an inch to define the slope of the printing. The beginner should pencil each letter in with the greatest care before inking in, avoiding the use of Indian rubber. When he has gained sufficient proficiency through practice, the pencil may be dispensed with. Students should remember that it is impossible to print after taking any violent exercise as hand will not be sufficiently steady.

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z.

a b c d e f g h i j k l m n o p q r s t u v w x y z

1 2 3 4 5 6 7 8 9 10 ¼ ½ ¾

Buildings. Bridges. Plan. Elevation. Section. Scale.

Scantlings of Rafters. Purlin. Tie Beams. Strap.

Bolt 1" diameter. Flat Arch. Relieving Arch. Ground line.

Bressummer. Slope 1 in 20. Wall-Plate. Rafter.

Weather Boarding. Ridge Pole. Ventilator. King post truss.

Angle Iron. Sheet Iron. T Iron. Calcutta. Allahábád.

Roorkee. Kashmere. Indus. Ganges. To Morádábád.

fr. Bareilly

Italic printing is well adapted for the information to be entered on ordinary Plates and Surveys.

To execute this, the beginner should rule three lines parallel to each other to regulate the heights of the small letters and capitals. The distance apart of these lines will depend on the sixe of the printing desired, but lines three and four sixtieths apart will be found convenient to start on. Parallel lines should then be ruled at intervals of about half an inch to define the slope of the printing. The beginner should pencil each letter in with the greatest care before inking in, avoiding the use of Indian rubber. When he has gained sufficient proficiency through practice, the pencil may be dispensed with. Students should remember that it is impossible to print after taking any violent exercise as hand will not be sufficiently steady.

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z.

a b c d e f g h i j k l m n o p q r s t u v w x y z.

1 2 3 4 5 6 7 8 9 10.

Buildings. Bridges. Plan. Elevation Section. Scale.

Scantlings of Rafters. Purlin. Tie-Beams. Strap.

Bolt 1" diameter. Flat Arch. Relieving Arch. Ground line.

Bressummer. Slope 1 in 20. Wall-Plate. Rafter.

Weather-Boarding. Ridge-Pole. Ventilator. King-Post Truss.

Angle-Iron. Sheet-Iron. T-Iron. Calcutta. Allahabad

Roorkee. Kashmir. Indus. Ganges. To Moradabad.

From Bareilly.

Italic printing is well adapted for the information to be entered on ordinary Plates and Surveys.

To execute this, the beginner should rule three lines parallel to each other to regulate the heights of the small letters and capitals. The distance apart of these lines will depend on the size of the printing desired, but lines three- and four-sixtieths apart will be found convenient to start on. Parallel lines should then be ruled at intervals of about half an inch to define the slope of the printing. The beginner should pencil each letter in with the greatest care before inking in, avoiding the use of india-rubber. When he has gained sufficient proficiency through practice, the pencil may be dispensed with. Students should remember that it is impossible to print after taking any violent exercise as hand will not be sufficiently steady.

SPECIMEN OF HAND-PRINTING.

A B C D E F G H I J K L M N O
P Q R S T U V W X Y Z
1 2 3 4 5 6 7 8 9 0
a b c d e f g h i j k l m n o p q
r s t u v w x y z

PLAN. ELEVATION. SECTION. SECTIONAL ELEVATION.
ALLAHABAD. ROORKEE. SAHARANPUR.
from Manglaur to Dehra. from Najibabad.

It is necessary for the Engineer to convey his ideas by good draftsmanship, but a good drawing can be spoilt by poor hand-printing. Hand-printing to look well must be even, and no style suits better for rapid work with an ordinary writing nib or pencil than the style here illustrated, which should be cultivated as opportunity permits in addresses to letters, rough sketches, field-books, &c.

3. If lines are drawn wrong, mark them lightly with one or two dashes; but as a rule omit all corrections of pencil work with rubber till the plan is inked in and then at one operation rub out all the pencil lines, Every use of the rubber raises the paper surface into a roughness in which dust catches and gets ingrained.

4. No attempt should be made to produce a finished pencil drawing, the outline only should be drawn in pencil and no shading or shadow lines as the lead rubs off and dirties the paper.

5. When about to draw a right line between two points, place the ruler as nearly as possible in the same position with reference to both and then see whether the line will pass exactly through both points, before drawing it on the paper with either pen or pencil. Also in drawing an arc through several points, try it with plain dividers, to see if the centre is exact before drawing the line.

6. All lines should be drawn sufficiently long at first, to avoid the necessity for subsequently producing them; a long line should never be obtained by producing a short one, unless some distant point in the prolongation has been first found by other means.

7. Whenever it is practicable lines should be drawn *from* a given point and *not* to it; and if there are several points, in one of which two or more lines meet, the lines should be drawn from that one to the others: thus, radii of a circle should be drawn from the centre to points in the circumference.

8 The larger the scale on which any problem, or part of one, is constructed, the less liable is the result to error. Hence all angles should be set off, and points determined by means of the largest circles which circumstances will allow to be described.

9. In determining a point by the intersection of circular arcs or straight lines, the radii should meet at that point at an angle of not more then 30°.

10. When one arc or straight line intersects another, as above, the second arc or line need not be drawn, but the *point* of intersection *only* should be marked, so as to avoid unnecessary lines.

11. Avoid setting off equal lengths on a given straight line by continual repetition of one such length, but mark off on the line a convenient multiple of the given length, and sub-divide it i.e., work from the whole to parts, not from parts to the whole; this is a great principle in surveying as well as plan drawing, and is especially to be observed in the construction of scales.

12. In laying off a length along a line with a scale, it is always well to check, either by reading off the distance along another part of the same scale, or by applying the scale so that it shall read backwards. This is a simple check and a very useful one, as in plotting a survey it may often prevent considerable unnecessary labour.

13. Every drawing should have one or more long lines put in first across the paper and at right angles to these; all new lines should be laid off from these guide lines, not from short lines of some part of the plan. The right angle guide lines should be laid with the compasses in the ordinary geometric way, not with the protractor. If a T-square and large set square is used, this should be more accurate than any other way if carefully managed.

Instructions for the preparation of finished Topographical Drawings.

7. **Drawing Paper.**—The drawing paper should be carefully examined to see which is the right side and that no mouldy spots exist. If any such spots are detected, the paper should be rejected, as it is impossible to paint over the discoloured spots. The paper is right side towards the draftsman when held up to the light and the name of the maker reads correctly.

(*a*) *Scales.*—Before commencing any large drawing, the scale on which it is to be made should be carefully constructed at the foot of the paper. All measurements should be taken from this scale. No discrepancy will then exist, when the paper is removed from the board, between the measurements on the drawing and the corresponding ones on the scale. Such discrepancy is often very considerable when separate pieces of paper are employed for the scale and drawing: drawing paper is very sensitive to atmospheric conditions, and often shrinks considerably after removal from the board. For purposes of computing areas the paper should be ruled up (in cobalt) into one inch squares.

The drawing.—The drawing should now be put in with fine pencil lines, which, when complete, may be inked in with a fine drawing pen and the best Indian ink. No thick ink lines are on any account to be drawn till all the colours have been laid on. Care should be taken not to overshoot the corners where two lines intersect and the lines should be kept as fine as possible.

Circles and arcs of circles should be inked in before straight lines. In drawing circles, care must be taken not to allow the point of the

compass to penetrate the paper, the holes thus formed are liable to become filled up with colour and cause an unsightly blemish. The fine outlines of the drawing having been inked in, the paper should be thoroughly cleaned with dry clean bread and india-rubber, but the latter should be used as sparingly as possible.

(*b*) *Flat washes.*—In laying on a flat wash the drawing board is always to be inclined so as to let the colour float downwards, the brush being only needed to give direction. If the paper is horizontal, the wash, remaining stagnant on one spot, deposits some of the solid colouring matter on the paper as a kind of precipitate, thus giving rise to unsightly blotches and cut shades. It is quite unnecessary to wet the paper before laying on a flat wash if the following directions are observed :—

Sufficient colour should be mixed to last for the whole of the wash required, any sediment should then be allowed to settle, and the clear solution poured of into another saucer. A wash should never be commenced without having a piece of blotting paper handy. A large brush should be used and the colour kept running across the paper, working it gradually down the slope, and no portion of the "working" edge of the colour should be allowed to dry up even for a second till the whole wash is completed. The brush if used full of colour and the colour carried down, stroke by stroke, will ensure a fine even wash. The brush should be replenished with colour as soon as half its contents are used up except towards the end of the drawing when only that quantity sufficient to cover the remaining surface is retained in the brush, Red lines should not be washed over, or the colour will run. When a flat wash is uneven, or contains a cut shade (probably from allowing that portion to dry), or it is required to take out lines, or washes of colour, which are mistakes in the drawing, use a small soft sponge dipped in water, but not too full, apply the sponge boldly but lightly, and have a piece of blotting paper at hand with which to blot off the moisture. Where the colour to be erased is near other colours which the sponge might also touch, an aperture should be cut in a piece of paper of the exact dimensions of the extent to be washed, the paper is then held firmly down upon the drawing, so that only the required portion of it is visible, and the sponge can then be applied without risk of soiling the adjacent parts of the drawing. The sponge should never be used, either for, or near to, thick ink lines; the ink is sure to run. Ink lines on tracing cloth can be taken out by means of a moist brush and some blotting paper. The spot operated upon, will, however lose its glaze, and any ink line drawn over it afterwards will be liable to run. When as is often the

case, a blot or small blemish in a flat wash of colour has to be erased and fresh colour to be afterwards applied, it is important to keep the texture of the paper as intact as possible, the india-rubber should, therefore, be passed very lightly over the previously slightly moistened spot, and this operation should be repeated till a perfectly clean surface is obtained. The colour is then to be stippled in by separate strokes, not washed in; as in this latter case, the rough surface of the paper produced by rubbing would take the colour unevenly, and cause an unsightly blotch.

(c) *Choice of tints.*—The main point to bear in mind is to preserve harmony in the drawing. Bright colours go with strong lines and bold printing while light shades, fine lines and unobstrusive printing go together.

8. **Conventional Signs.**—It is obvious that some convention or method is desirable to obtain a uniform representation of each material or object by a colour or sign The conventional colours and signs given below include those adopted by departments in India (subject to corrections). Only the most important conventions are given, but there are many others which are used in special branches, such as Irrigation and Military Surveys, the details of which can be obtained from the various conventional charts. If any special signs or abbreviations are used, a table showing their meaning should be attached to the plan drawing.

LIST OF GENERAL COLOUR CONVENTIONS IN USE.

Hills	...	Brown (Burnt Umber).
Sand hills	...	Ditto.
Natural drainage ...	...	Black.
Tanks or jhils	...	Cobalt blue if perennial, otherwise black.
Natural ravines and dry nalas	...	Black.
Rivers and streams ...	...	Cobalt blue if perennial, otherwise black.
Village sites { Brick houses	...	Vermilion.
Village sites { Mud houses	...	Brown also vermilion.
Roads, metalled ...	...	Vermilion.
Roads, unmetalled ...	...	Vermilion (Broken lines).
Railways	...	Black.
Canals	...	Blue.

9. CONSTRUCTION OF SCALES.—When anything which has to be represented on paper is so large that it would be inconvenient to make a full-sized drawing of it, the drawing, or map, is made to another scale; that

is, each line in the plan, using this word as a general term, is made with a fixed and known proportion to the line it represents.

Suppose, for example, that in a drawing of a house a line one inch long represents in plan a wall 100 feet long. Then, if the drawing is "drawn to scale," every other detail of the house will be represented by lines drawn in the same proportion. This proportion is called the scale of the drawing, and in this case the drawing is said to be drawn to a scale of 100 feet to an inch. Further, it is evident that the actual length of each piece of the building is 1,200 times the length of the line which represents it in the drawing; or every line in the drawing is $\frac{1}{1200}$th part of the corresponding line in the object. This fraction which represents the proportion of the drawing to the object, is called the "*Representative Fraction*," and this fraction should be entered in a conspicuous place on every plan. The student must clearly understand what is meant by the representative fraction, to find which he must reduce the number of units represented by 1 inch in plan to inches. This will be the denominator of the fraction. The numerator will invariably be 1.

For example—

Find the representative fraction of scale of one furlong to an inch.

The denominator is then $12 \times 3 \times 220 = 7{,}920$, and the representative fraction is $\frac{1}{7920}$.

In addition to the representative fraction, some means must be given by which any distance on the plan may be measured off, and the real length of the object it represents may be ascertained. This is done by means of a graduated straight line called the SCALE.

Scales may be divided into—

(1) Plain Scales.
(2) Comparative Scales
(3) Diagonal Scales.
(4) Vernier Scales.

Before proceeding to consider the construction of scales it will be necessary to show how a given line can be divided into any desired number of parts, as this construction is frequently required in the construction of scales.

To divide a given line AB into five equal parts (Plate VI., Fig. 1).

From the point A in the given line AB, draw a line AC making any convenient angle with the line AB. This angle should not be too acute. Along AC mark off five equal divisions 1, 2, 3, 4, 5. Join 5B. Through 1, 2, 3, 4, draw lines parallel to 5B, cutting AB in P_1, P_2, P_3, P_4;

These points will divide the line AB into five equal parts. Care should be taken to arrange the length of the divisions taken along AC in such a manner that the line 5B may be nearly at right angles to AB. If the angle at which the line 5B meets AB is too acute, it will be difficult to fix the points of intersection P_1, P_2, P_3, P_4, exactly.

10. **Plain Scales.**—In all scales it is evident that if they fulfil the functions explained above, the unit of length of the scale must bear the proportion shown by the representative fraction to a real unit, and any length on the scale the same to the real length.

We will now give a few examples embodying the chief points to be kept in mind in the construction of scales.

Example 1.—To construct a scale of 100 feet to an inch to read to 10 feet. (Plate VI, Fig. 2).

Scales are usually made about 6 inches long. For this case 6 inches will be found convenient as it represents 600 feet.

Draw a line 6 inches long and divide it into six equal parts.

The left hand division is always used to show the smallest unit required, in this case 10 feet. Divide this division into 10 equal parts. These will each represent 10 feet. Ink in two lines for the scale $\frac{4}{60}$th of an inch apart, the bottom one being darker than the top one. Draw perpendicular lines $\frac{8}{60}$th of an inch high to show the primary divisions, and $\frac{4}{60}$th of an inch high to show the secondary sub-divisions. The right hand point of the left hand division is invariably marked 0; the secondary sub-divisions starting from that point are marked from right to left, and the primary divisions from left to right. Print in the title of the scale and the representative fraction, and the unit (feet) which the primary and secondary divisions represent. On the right hand side of *Fig.* 2 are shown convenient distances at which the various lines for construction and printing may be drawn.

Example 2.—The representative fraction of plan is $\frac{1}{60}$, construct a scale to read to feet. (Plate.VI, Fig. 3)

Here 60 inches, or 5 feet, represent one inch, and 6 inches on the scale will represent 30 feet. Lay down 6 inches and divide it into three parts and the left hand sub-division into 10 parts. Finish as in Example 1.

Example 3.—To construct a scale of 13 yards to an inch, to read to yards (Plate VI., Fig. 4).

Here do not follow the too common error of laying down inches and dividing the left hand inch into 13, and numbering the others 13, 26, 39, &c., so that nothing can be conveniently measured on it, but proceed thus. Here 13 yards equal 1 inch, therefore 6 inches represent 78 yards. The

nearest next numbered scale to this will be 70 yards, i.e., 10 units to left, and 60 to right, of zero. So, as 78 : 70 : : 6 : 5·39. Lay down 5·39 inches and divide into 7 parts, and the left hand part into 10. Representative fraction, $\frac{1}{13 \times 3 \times 12} = \frac{1}{468}$.

For the method of laying off a distance of 5·39 inches, *see* Diagonal Scales, Example 13.

Example 4.—To construct a scale of 2 miles to the inch, showing miles and furlongs. (Plate VI., Fig. 5).

Here 6 inches = 12 miles, but 1 mile to left and 11 miles to right would not look well. So, as 12 : 11 : : 6 : 5·5 inches. Lay down 5·5 inches, and divide into 11 spaces, and divide the right hand space into 10. Representative fraction, $\frac{6}{12 \times 5280 \times 12} = \frac{1}{126720}$.

Example 5.—To draw a scale of 6 inches to a mile to read to yards. (No figures are given for Examples 5, 6, 7 and 8.)

It will be most convenient to draw primary divisions to show 1,500 yards and secondary sub-divisions to show 100 yards. Six inches represent 1760. So 17·6 : 16 : : 6·0 : 5·45.

Lay down 5·45 inches and divide as usual. Representative fraction, $\frac{6}{1760 \times 12 \times 3} = \frac{1}{10560}$.

Example 6.—To construct a scale of 8 inches to the mile, in paces of 30 inches.

Here 8 inches = 5,280 feet, or $\frac{5280}{2 \cdot 5}$ = 2,112 paces. Then say, 1,600 paces is the length chosen. As 2112 : 1600 : : 8 : *x*, *&c.*

Example 7.—To construct a scale of $\frac{1}{20000}$ showing chains of 100 feet.

Here 1 foot = 20,000 feet, and 6 inches = 10,000 feet, or 100 chains. Then 110 chains will be the length of the scale. So, as 100 : 110 : : 6 : &c.

Example 8.—The representative fractions of two plans of a Russian fort are $\frac{1}{800}$ and $\frac{1}{1250}$; construct a scale of French toises for the former, and one of Russian archines for the other. The toise = 2·13142 yards, the archine = ·7777 yards.

In the first, 1 toise or 2·13 yards = 800 toises. Reduced to inches, 76·73 inches on plan equals 800 toises, or 7·67 inches = 80 toises. Thus 60 will be nearest suitable length for scale, and 80 : 60 : : 7·67 : &c., &c. The other is just similar.

Example 9.—In a rapid reconnaissance, when time will not admit of distances being measured by a chain or perambulator, they can be roughly measured by time. If the rate of a horse is known, when trotting or at a gallop, &c., a scale can be made by which distances are at once taken off from simple observations on the time which has elapsed. (Plate VI., Fig. 6.)

Suppose a scale of 6 inches to a mile ($\frac{1}{10560}$) is required, adapted to the pace of a horse which trots at the rate of 240 yards a minute.

Then in 9 minutes a horse will trot 2,160 yards. Make a scale of 6 inches to a mile to show 2,160 yards. The length of this line will be $10560 : 2160 \times 36 :: 1 : 7{\cdot}36$.

Lay off a line 7·36 inches long and divide it into 9 equal parts. Each part will represent the distance over which the horse travels in a minute, or 240 yards. Sub-divide the left hand division into 6, which will then read to 10 seconds.

11. **Comparative Scales.**—When the given scale of a plan reads in a certain measure, *and it be desired to construct a scale* for the plan reading in some other measure, this new scale is called a comparative scale.

Thus if the scale of the plan of a French building reads in decimetres, and it is desired to take measurements off the plan in feet, a comparative scale must be constructed. The main point to bear in mind is that the repesentative fractions of the two scales must be the same.

Example 10. The scale of an Indian plan is drawn in Haths. It is found by measuring the scale that one inch represents 6·75 Haths. It is required to draw a comparative scale of feet.

(Hath=18 inches.) (Plate VI, Fig 7.)

The representative fraction is $\frac{1}{6{\cdot}75 \times 18} = \frac{1}{121{\cdot}5}$.

Take a length of scale to show 60 feet, then

$$121{\cdot}5 : 720 :: 1 : 5{\cdot}92.$$

Lay down a line 5·92 inches long and divide it into 6 parts, and the left hand division into 10 parts. These now represent feet.

Example 11.—The scale of a map of France is in French leagues (1 French league = 4262·84 English yards). It is found by measuring the scale that 3·75 inches represent 25 leagues. Construct the corresponding scale of English miles. (Plate VI., Fig. 8.)

Here 25 leagues $= \frac{4262{\cdot}84}{1760} \times 25 = 40{\cdot}5$ miles.

Consequently, 40·5 miles are represented by 3·75 inches, so the scale may show 110 without being very long. So, $40{\cdot}5 : 110 :: 3{\cdot}75 : 6{\cdot}81$.

Divide then a line 6·81 inches long into 11 equal parts, to show tenths of miles; sub-divide the first primary division into 10 equal parts, to show miles.

Example 12.—A map is drawn to a scale of 2 miles to an inch ($\frac{1}{126720}$). Construct a comparative scale of Russian versts. (No figure is given.)

1 Russian verst = 1166·6 English yards.

As the two scales must have the same representative fraction, this question is at once reduced to that of making a scale of $\frac{1}{126720}$ to show versts. But it can also be found directly as follows:—

As one inch represents 2 English miles, and 2 English miles $= \frac{1760\times 2}{1166\cdot 6}$ Russian versts, therefore one inch will represent $\frac{1760\times 2}{1166\cdot 6} = 3\cdot 02$ versts. The scale will be best 21 versts long.

$$\frac{1760\times 2}{1166\cdot 6} \text{ versts} : 21 \text{ versts} :: 1 \text{ inch} : x \text{ inches.}$$

$$\therefore x = \frac{21\times 1\times 1166\cdot 6}{1760\times 2} = 6\cdot 96 \text{ inches.}$$

Set off a line 6·96 inches long, and divide it into 21 parts, each part will represent a verst. Divide left hand space into quarters.

In *Plate* VII., *Fig* 1, is shown another sort of comparative scale which is sometimes useful in enlarging or reducing a plan.

If the same distance on two plans on different scales be represented by AB and AC, then all lines parallel to BC will cut off lengths from A in the proportion of AB : AC. Therefore, taking any measurement on one plan in the compasses, and applying it from A along its line, say AB, the length of the same measurement on the other plan will be found by moving the right leg of the compasses down the cross line AC to C.

12. **Diagonal Scales.**—It will be seen from the preceding examples that some method of representing a decimal notation is often required. Further, on a plain scale it is only possible to read in two dimensions, such as yards and feet, inches and tenths of an inch, &c. It may be desired to read in three dimensions, such as yards, feet and inches, tenths of inches and hundreths of inches. For this purpose a diagonal scale is used.

Example 13.—To draw a diagonal scale of inches, to read to one-hundreths of an inch. (Plate VII., Fig. 2.)

Draw a line 6 inches long and divide it into 6 parts. Divide the left hand sub-division into 10 parts, and at the extrame left raise a perpendicular. On this perpendicular lay off 10 equidistant points, and through them draw 10 lines parallel to the scale line. Divide the top line in the left hand sub-division into 10 parts. Draw lines straight up through the divisions right of zero, but to the left of zero, draw diagonal lines to one division to the left on the top line, and number as shown in the figure.

Then it is evident that each division we move along the bottom line from 0 to 10 we get $\frac{1}{10}$, $\frac{2}{10}$, &c., further from zero, but if we move along

one of the diagonal lines, say from zero to the first division to the left on the top line, then every time a fresh line is crossed, we have moved $\frac{7}{100}$th of an inch further from zero.

The cross marks on the figure show 3·60 and 5·32 inches respectively reading from the top.

The main point to remember in drawing a diagonal scale is, that the left hand subdivision must be divided into the number of units of the second dimension required, and the number of parallel lines drawn above the scale line must be the same as the number of units there are of the third dimension in a unit of the second dimension.

For example, if it was required to draw a diagonal scale of yards, feet and inches, the primary divisions would be yards, the left hand division would be divided into 3 for feet, and the number of parallel lines required would be 12.

Latitude and Longitude.—Diagonal scales are invariably used for plotting data on geographical maps and since geographical maps are divided up into graticules of some integral part of degrees, a scale of degrees, minutes and seconds will be required. Take for example a standard map of India on the scale of 1 inch to a mile which is 15′ in longitude and 15′ in latitude; the scales suitable for plotting would be of 5′ each. To make the scales, take off one-third of the length in latitude and in longitude, divide each into fifths and number from the left hand side 1, 0, 1, 2, 3, 4. The space 1 to 0 divide into sixths and with 10 divisions laterally each diagonal part will be $\frac{1}{10 \times 6}$ or $\frac{1}{60}$ of a minute $=$ 1 second. It must be noted that except at the equator the scales for longitude and latitude will be of different lengths.

13. **Vernier Scales.**—Vernier scales are sometimes used instead of diagonal scales. The principle on which they are constructed is as follows :—

If we have any length of scale representing n units of measurements and divide it into n equal parts, each part will represent one unit. If now we take a line equal to $(n + 1)$ of these units, and divide it also into n parts, each minor division will be equal to $\frac{n+1}{n}$ units, and the difference between one minor division of the last and one minor division of the first will be $\frac{n+1}{n} - \frac{n}{n} = \frac{1}{n}$ of the original unit. And similarly, the difference between two divisions of the one and two of the other will be $\frac{2}{n}$ of a unit—between 3 of one and 3 of the other $\frac{3}{n}$, and so on.

Example 14.—To construct a scale of $\frac{1}{100}$ to show feet and tenths. (Plate VII, Fig. 3)

Let the scale be drawn in the ordinary way, but sub-divided throughout its entire length; each sub-division shows one foot; set off to the left, on the upper line, a distance equal to 11 sub-divisions commencing from the zero of the scale; divide this into 10 equal parts as in the figure. Since 11 sub-divisions of the plain scale have been divided into 10 equal parts on the vernier scale, each division on the vernier will represent $\frac{11}{10} = 1{\cdot}1$ of the sub-divisions on the plain scale, and as these show feet, each division on the vernier will show 1·1 foot; consequently the several distances from the zero of the scale to the successive divisions on the vernier will show 1·1, 2·2, 3·3, 4·4, 5·5, 6·6, 7·7, 8·8, 9·9 and 11 feet. The scale is used thus.

Let it be required to take off 26·7 feet.

Now the seventh division on the vernier will give us a reading of 7·7 on the scale.

Subtract 7·7 from 26·7, the remainder is 19; place one point of the compasses on the 19th sub-division on the upper line of the plain scale, and the other on the 7th division of the vernier; this distance represents 26·7 feet.

Vernier scales, when applied to instruments, are constructed so that the vernier can be made to slide on the main scale. In this case it is more convenient if the vernier and scale read the same way, and for this purpose it is necessary to take the $n-1$ units to divide n. The difference is just the same; it is $1 - \frac{n-1}{n} = \frac{1}{n}$ of a unit.

Example 15.—It is required to measure the rise and fall of the mercury in a barometer to the 100th of an inch. (Plate VII., Fig. 4).

The main scale is divided into inches and tenths of inches. For the vernier take 9 sub-divisions and divide this distance into 10 parts.

When the top of the mercury falls between any two of the divisions on the main scale, it is only necessary to slide the zero of the vernier to fit with the top of the column, and read the number of the division that coincides with one of the plain scale. Here the reading is 28·97 inches. The difference between top of mercury, or zero of vernier, and 28·9, is that between 7 divisions on the fixed and 7 on the vernier, scale, or $\frac{7}{100}$. If the student will just mark off the divisions of the vernier on a separate slip of paper, and slide this about to fit any different height of mercury, the process will be immediately clear.

Example 16.—Construct a moveable vernier to read minutes to a surveying instrument, of which the arc is graduated to degrees and half degrees. (Plate VII., Fig. 5).

Here the smallest division on the graduated arc is 30 minutes. Take a length of 29 minutes, and divide it into 30 for the vernier. In reading

read to nearest half degree, and add the number of minutes shown by the vernier. In this case it is 2° 30′ + 11′, or 2° 41′.

14. **Slide Rule,*** [*Fig.* 6, *Plate* VII.]—In connection with scales this may not be an inappropriate place to introduce an explanation of the Slide rule. The rule is exceedingly simple in principle, as it is merely graphic logarithms.

Take any length as PQ, and divide it into 10 equal parts, and again extend the same length to right as QR, divided in same way into 10 parts and number continuously to 20. The more minutely this can be again decimally divided the better. Now the logs of the successive numbers are as in margin. If then PQ be taken as the graphic value of log 10, or as 1 the values of logs 1, 2, 3, &c., will be as shown by the figures below the scale, all counted from left hand, or P. It will be noted that log 20 is the same as log 10 + log 2, and log 30 as log 10 + log 3, &c. Thus the 10th divisions (shown thick) of the right half are the same as the divisions of the left half, as of course they must be, since they are the logs of multiples of 10, and are thus formed by adding PQ, or log 10.

1=0·000
2=0·301
3=0·477
.. ..
10=1·000
11=1·041
12=1·079
.. ..
20=1·301
.. ..
30=1·477
&c., &c.

The slip marked A is then nothing but a graphic log table, and this is the scale A of the rule. B, which slides on this, is exactly the same. To multiply any two numbers we take the log of one on A, the other on B, and add them. Thus in example 3×2. Slide B clear of log 3, take log 2 on it, and evidently opposite the end of log 2, or the figure 2 on B, there is log 3 + log 2 on A, which accordingly is found to be log 6. Similarly at log 5 on B, is log 3 + log 5, or log 15 on A, and so for any multiple of 3. The same figure will show the working of any division of which the quotient is 3. Thus from log 12 on A, take away log 4 on B, result is 3 on A and so on.

The student will probably at once say, but I want to multiply larger figures than 100, which seems to be the limit of this, indeed, a product of 100 is the limit, as this is all that can be read on A. But as the notation is decimal, this 100 can stand for a million, or million million, if the sub-divisions can be carried out. The weakness of the slide rule is that there is so little room for these sub-divisions.

The student may take the method for granted, and work the slide rule as he finds it graduated; counting the first division, *i.e.*, to 2, any decimal multiple of 2 he likes, 200 or 2 million, but counting straight on from that,

* For stadia slide rule see Part II.

start all the other figures the same multiple, and noting that in the right hand half, to save figures, the 20 is usually numbered 2, the 30 as 3, and so on.

The method of division is no mystery. Taking the scale A as in *Fig*. 6, *Plate VII.*, it is desired to divide so that the first division 1 to 2 shall represent log 20. This will be 1·301, but as log 10 will be 1·000, it will lie to *left* of A. But the student will see that 10 to 20, which is the same as A to 2, has log 10 to left, and 20 does in fact read 1·301, and therefore, he has only to repeat the division of QR in PQ as its sub-division, and similarly, the division of the next length RS, arranged from the logs of 20 to 30 by the upper scale repeated in QR, will be its sub-division, and so on.

The slides A and B explained above are the simple numbers, but it will be clear that if the figure 2 had been written opposite the number representing the log of the square of 2 on the original even scale PQ, the figure 3 opposite that of the square of 3, &c., the slide so made which is D on the ordinary slide rule, would be a graphic representation of the logs of the squares of the numbers entered on it, and if log of a number and log of its square are added by sliding, the result must be log of the cube. Slide C is the same as A and B, and therefore C and D give cubes.

Similarly, a scale of any multiple of the primary numbers can be made, say of 13 items 1, 2, 3, &c., it is only necessary to write 1, 2, 3, &c., opposite the number on the simple scale representing log 13, 26, 39 &c.

Vide No. CCXI.,* "Professional Papers on Indian Engineering," Vol. V., 2nd series, for application of this to the formulæ finding the scantlings of timber for roofs. The difficulty of using the slide rule will be seen by supposing B slide to 31, and the product of 31 and 21 required. The result will show as a little beyond 65; then by actual multiplication of the units, the last figure is known to be 1, and also it is known that result must be 3 figures, so it is found to be 651. Take 345×345, all that can be read is that it is nearly 1,200 counting on from 345 on scale A. It is really 119,025, so that the worker has to supply his own number of figures, as well as the details of the figures.

Geometrical Drawing.

Examples.

1. Construct a scale of $\frac{1}{1760}$ to read to 20 feet.
2. Construct a scale of 8·5 feet to an inch to read to single feet.
3. Construct a scale of metres $\frac{1}{240}$ (1 mėtre = 1·0936 yards).

* Also No. CLXIII., Vol. IV., "Professional Papers," 1st Series.
" No. CCXXV., Vol. VI.

4. Finding that the distance between two points on a Swedish map is 7 inches and the real distance on the ground 5,000 alners. Construct a scale of feet (1 alner = ·6493 yards).

5. Construct a scale 22 yards to an inch, on which single yards can be measured.

6. Construct a scale of 6 inches to a mile, showing chains (100 feet).

7. The distance beteen Roorkee and Saharanpur is 23 miles, and measures on a map 13·67 inches. Draw the scale of the map showing miles and furlongs.

8. Construct a scale of $\frac{1}{33000}$ to show versts (1 verst = 1166·68 yards).

9. On a plan 3·1 inches represent 47 feet. Construct a scale.

10. The plan of a building is a square of $3\frac{1}{2}$ inch side, the length of the diagonal represents 100 feet. Construct a scale to read to inches.

11. Draw a scale of miles and furlongs, in which $1\frac{1}{2}$ furlongs equal $\frac{1}{3}$ of an inch.

12. Construct a diagonal scale of 9 inches to a mile to read to furlongs.

13. Construct a scale of 5 miles to an inch and a comparative scale of Russian versts (1 verst = 1166·68 yards).

14. Draw a diagonal scale to read to the thousandth of a foot.

15. A Prussian fathom contains 6 Rhenish feet, each equal to 1·0297 English feet. Construct a scale of fathoms $\frac{1}{231}$, showing feet diagonally.

16. An Englishman, wishing to examine a Spanish plan, finds only a scale of Spanish palms, 20 to an inch; supply him with a corresponding scale of English feet, taking the palm as ·634 of an English foot. Show 50 feet.

17. Draw scales of $\frac{1}{1500}$ to represent English feet, French métres and Greek cubits. 1 metre = 3·27 feet, 1 cubit = ·45 métre.

18. Construct a scale of 6 inches to a mile, to measure furlongs and diagonally spaces of 60 feet.

19. A map is 36 inches long and 30 inches broad, it represents an area of 25 acres; draw the scale of the map to show poles, yards and (diagonally) feet; 4,840 square yards = 1 acre.

20. Required a scale of Russian archines for a plan on which the breadth of a river, really 50 sachines in width, is represented by 12 English inches, 3 archines = 1 sachine = 2·3332 English yards.

21. Construct a scale of 8 inches to 1 mile to read to 20 paces, and by a vernier to 5 paces. 1 pace = 30 inches.

22. The distance between two points, 1 Austrian mile apart, is represented on a map by 2·66 English inches. Construct a diagonal scale of English miles. 1 Austrian mile = 3·3312 English miles.

23. Construct a scale off $\frac{1}{15000}$ to take of intervals of time adapted to the trot of a pony, which goes over 180 yards per minute at a fast trot. Show 10 minutes.

24. A horse passes over about 280 yards per minute at a gallop. Construct a scale of $\frac{1}{200000}$ adapted to time. Show 10 minutes.

25. On a plan 1,200 yards are represented by 15 inches. Draw a comparative scale of French metres (1 metre = 1·0936 yards).

26. The representative fraction of scale on a Russian map is $\frac{1}{1700}$. Draw a comparative scale of French metres (1 metre = 39·37 inches).

27. A distance on a French map which is known to be 3 miles measures 18 inches. Taking a pace to be 32 inches, construct a scale of paces for the map.

28. Construct a vernier scale of $\frac{1}{100}$ to show feet and inches.

29. Construct a scale of $\frac{1}{275}$ to show poles and yards, and by a vernier to read feet.

30. Construct a diagonal scale of $\frac{1}{50}$ to show metres, decimetres and centimetres (1 metre = 3·28 feet).

31. A scale of 4 inches to the mile is attached to a map. On this I find the distance between two points to be 1 mile 5 furlongs. I measure the same distance on the ground and find it to be 1 mile 3 furlongs. Knowing the survey to be correct, construct a correct scale to the map to read to miles and furlongs.

32. Construct a scale of chords and by means of it set off from a line an angle of 75°.

33. One degree on a scale is represented by $\frac{3}{10}$ of an inch. Construct a scale showing degrees and quarter degrees, with a movable vernier to read minutes.

34. You are given a survey of a portion of country drawn to a scale of 16 inches to a mile. The paper it is on measures 32 inches long by 26 inches broad. Find the area of the country, and the area of paper required to copy the survey to a scale of 12 inches to a mile.

What are the representative fractions of the two scales?

35. A map is 40 inches long and 27 inches broad; it represents an area of 50 square miles. Draw the scale of the map to show miles, furlongs and diagonally chains.

16. **Geometrical Construction.**—The following problems are a few of the most useful ones connected with plan drawing, and as many of them are useful in ground tracing and field survey operations, they ought to be clearly impressed on the mind, so that the student may be prepared

to substitute for the compasses a cord fixed at one end when describing arcs in the field, and a measuring tape when setting off distances. A set of examples are added at the end of the Chapter for practice, and the student should go carefully through them, and draw them on a separate plate, and to a different scale. A few problems illustrating the use of the sector are also given.

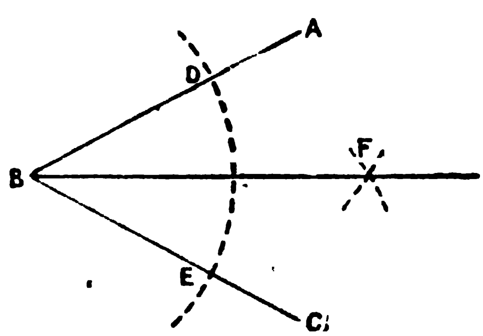
Note.—In working the examples, the 'Lines of Construction' (i. e., those used only to obtain the results) are to be *dotted* in, or drawn very fine, and in the case of any figure which has to be found, the lines containing it may be made somewhat *thicker* than usual. Lines, figures, &c., which are given, are to be drawn with lines of customary thickness, *thin* and continuous.

Problem I.

(*a*) *To bisect a given angle.*

Let ABC be the given angle (*Fig.* 1). Take equal lengths BD and BE along BA and BC. From D and E as centres, with equal radii, describe arcs of circles, intersecting in F. Join BF, this line bisects the angle.

Fig. 1.

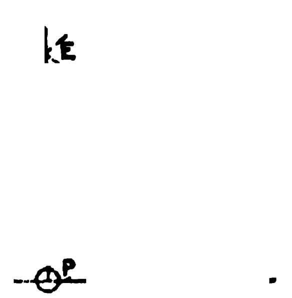


Problem II.

(*b*) *Through a given point to draw a line perpendicular to a given line.*

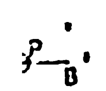
1. When the point P is in the given line AB, and not near either end (*Fig.* 2), set of equal distances, PC, PD, in AB; from C and D as centres, with any convenient radius, describe arcs intersecting in E, draw the line PE, which will be the perpendicular required.

Fig 2.



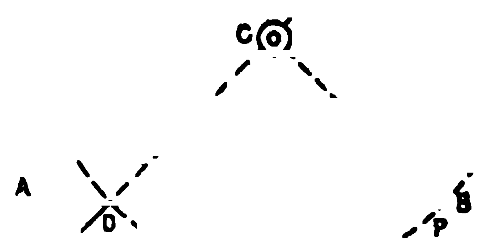
2. *Another method.*—From the point P (*Fig.* 3) set of *four* units, taken from any convenient scale of equal parts, along AB to C, and from P as a centre, with a radius of 3 of the same units, describe an arc, also from C, as centre and radius 5 units, describe another arc to intersect that just described in D; join PD; this is the perpendicular required. The angle CPD must be a right angle, since $3^2+4^2=5^2$.

Fig. 3



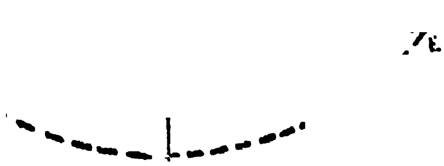
3. When the point P is at one end, or nearly so of the given line (*Fig.* 4). Assume any convenient point C not in AB. From C as centre,

Fig 4.



and with radius CB, describe an arc cutting AB in D, and a diameter drawn through D and C in E. Join EB, this will be perpendicular to the given line AB.

Fig. 5.

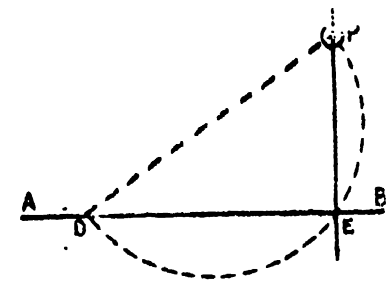


4. When the point P is not in the line AB (*Fig*. 5). From P as centre, and with any convenient radius, describe an arc, cutting the line AB in D and E. From these points as centres, and with any radius describe arcs intersecting in F, join PF, it is perpendicular to the line AB.

5. When the point P is not in the given line, and too nearly opposite one end of it to allow of No. 4 being employed. Draw a line PD *Fig*. 6)

from the given point to meet the given line AB at an angle of about 40° or 50°; on this as a diameter, describe an arc of a semicircle to cut the line in a point E; the line PE joining this point E with the given point P will be the required perpendicular.

Fig. 6.



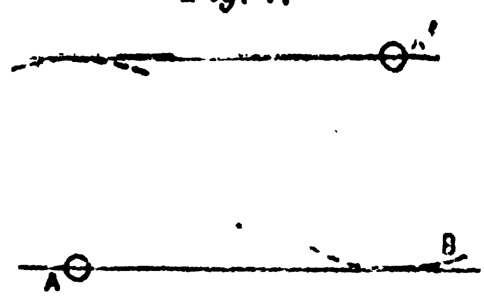
6. If the point is very distant from the line and all the above-mentioned methods are inconvenient, any perpendicular having been first traced, a line may be drawn through the point parallel to it and will be perpendicular to AB; thus also any number of perpendiculars may be traced by drawing lines parallel to any one of them.

PROBLEM III.

(*c*) *To draw a line through a given point parallel to a given line.*

Place one point of the compasses in A′ (*Fig.* 7), the given point, and open them till the other point (or pencil leg) would trace an arc *touching* but not *cutting* AB: from any point A in AB, as far off as possible from A′, as a centre, and with the same radius, describe an arc on the same side of AB as that on which A′ lies, then the line drawn through A *touching* this arc will be parallel to AB.

Fig. 7.

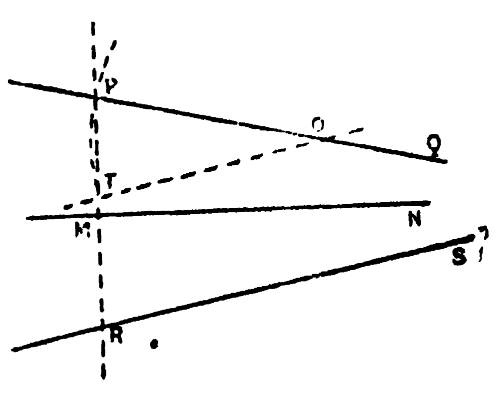


This construction should always be used whatever may be the length of the line AB; the perpendicular distance of A′ from AB is thus obtained with greater accuracy than by any other construction, since the eye can judge of the contact of an arc and straight line to ·005 of an inch.

PROBLEM IV.

(*d*) *To determine the direction of the line which would bisect the angle contained by two straight lines intersecting beyond the limits of the drawing.*

Fig 8.



Let PQ and RS (*Fig.* 8) be the lines. In PQ take a point O; draw OT parallel to RS; make OT equal to OP; join PT and produce it to meet SR in R; draw MN bisecting PR at right angles. MN, if produced, would pass through the point of intersection of PQ and RS, and *bisect* the angles between them.

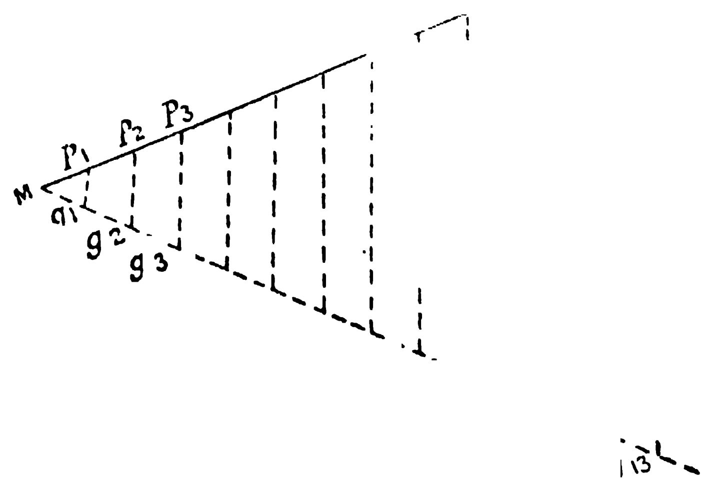
PROBLEM V.

(e) To divide a line into any number of equal parts.

1. The most expeditious mode of dividing a line into any number of equal parts is as follows :—

From the extremity M (*Fig.* 9) of the line MN to be divided, draw

Fig. 9.



an indefinite line MA at any angle, not too acute, to MN. From M set off along it equal distances $Mg_1, g_1\, g_2, g_2\, g_3$, &c., up to $g_{12}\ g_{13}$, as often as there are to be equal divisions of the given line,—in this case 13.

Join N and g_{13}, and through the other divisions g_1, g_2, g_3. &c., draw lines parallel to Ng_{13}, and intersecting the line MN in the points p_1, p_2, p_3 &c., these are the required points of division. It will be observed that any distance whatever may be used to set off along the oblique line NA, all that is needed being 13 equal spaces commencing from M, and that the lines determining the equal divisions do not necessarily intersect the given line at right angles.

2. When the number (n) into which the line is to be divided is small, open the compasses to what *appears* to be the nth part of the line, step this distance along the line from one end, and if it be found to exceed or fall short of the nth part, correct the opening by diminishing or increasing it by the nth part of the error and repeat the trial till the exact nth part be ascertained.

With a little attention it will be found that two or three trials are generally sufficient; but the process may be shortened by attending to the following rule :—If n can be resolved into two factors p and q, one of which, p, is any power of 2, as 2, 4, 8, &c., the line should be first

bisected (which can be always done by two trials); each part should be again bisected, and so on till the line is divided into p parts ; each of these again may be divided into q parts, the qth part being obtained by trial, as above.

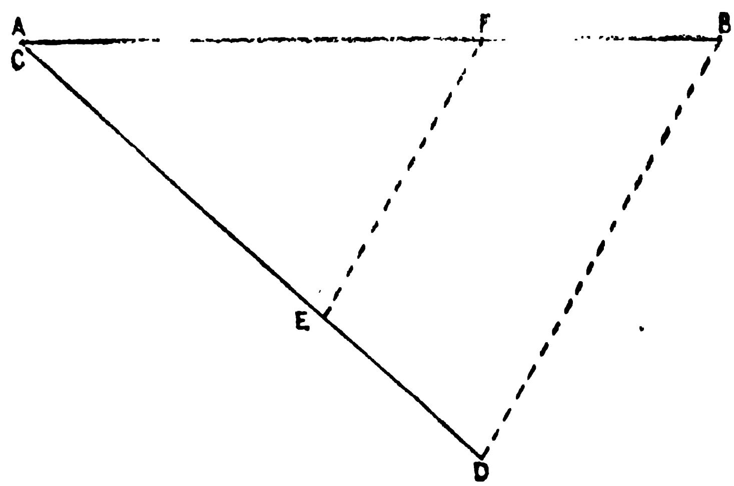
In making scales, the larger divisions should always be found in this manner, but the ultimate divisions should be found as explained in the first method.

PROBLEM VI.

(*f*) *To divide a line proportionally to another.*

This problem may be solved in a manner precisely similar to the first method given in Prob. V. Draw the given line AB (*Fig.* 10), making any angle not too acute at the point A with the line AD, which is divided into two parts in the point E. Join BD, and through E draw EF parallel to

Fig 10.



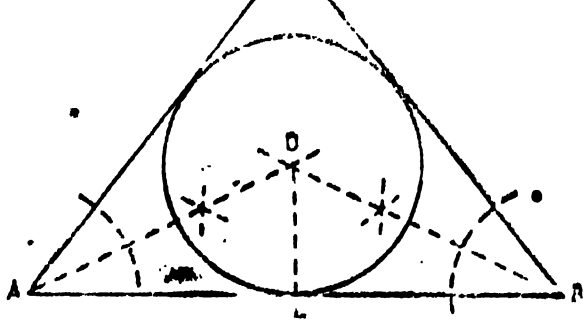
BD, then AB is divided proportionally to CD.

PROBLEM VII.

(*g*) *To inscribe a circle in a triangle.*

Let ABC be the triangle (*Fig.* 11). Bisect the angles A and B by the lines AD, BD meeting in D, which will be the centre of the required circle. From D draw DE perpendicular to AB, and DE will be the

Fig 11.



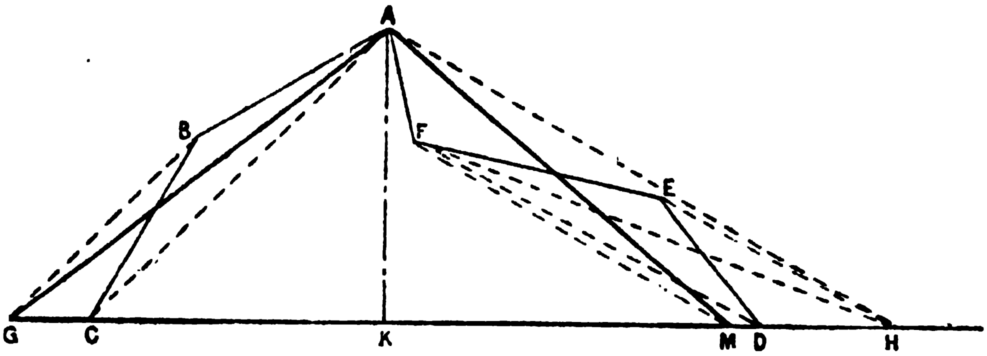
radius of the required circle.

PROBLEM VIII.

(*h*) *To reduce a given polygon to a triangle and thus to find its area.*

Let ABCDEFA (*Fig.* 12) be the given polygon. Produce CD, both ways, and assume the angular point A as the vertex of the required

Fig. 12.



traingle. Through B, draw BG, parallel to a line joining AC, then (by Euclid I., 35) the triangle AGC contains the same area as the triangle ABC. This arrangement has now reduced the number of sides of the polygon by one, as AG has been substituted for AB and BC, and GC and CO are in the same straight line. Draw EH parallel to a line joining F and D and FH, then the line FH has been substituted in a similar manner for the lines FE and ED. The polygon is now reduced to one having four sides AG, GH, HF and AF. Again, draw FM parallel to a line joining A and H, and join AM, the triangle AGM is equal in area to the given polygon. To obtain its area draw AK at right angles to GD, and having measured GM and AK, the area is at once found from the formula—

$$\text{Area} = \frac{AK \times GM}{2}$$

17. Examples for Practice.

1. From one extremity of a line 3 inches long, draw a perpendicular 2 inches long without producing the line. Base the construction on geometrical principle.

2. Find, by construction, a mean proportional between two lines 2·4 and 3·8 inches long, respectively.

3. A line 5 inches long is divided into 6 equal parts, draw parallel lines half an inch apart through the divisions of the given line.

4. Construct a square of 5·36 square inches area, without extracting the square root of 5·36.

5. Divide a line 3 inches long into 7 equal parts.

6. Make a triangle of which the sides are 3·5, 1·75 and 2·5 inches, respectively.

7. Describe a square equal to the difference of two squares whose sides are 3·25 and 1·94 inches.

8. Describe a rectangle equal to the triangle in *Example* 6.

9. Find a line which shall have the same ratio to a line 1·5 inches long that 3 inches has to 1·75 inches.

10. Given a circle, or an arc of a circle, to find its centre.

11. Describe upon a given line 2 inches long as a base, an isosceles triangle having a vertical angle of 30°.

12. Draw a circle circumscribing a triangle, of which the sides are respectively 4, 5 and 6 inches.

13. Construct a square equal to a triangle, of which the sides are respectively 1·5, 2 and 2·25 inches.

14. Draw arcs of 70° and 133° with radii 1·7 and 2·2 inches, respectively and a third arc, radius 4 inches, to touch the first two arcs; mark the points of contact.

15. Make a regular heptagon on a side of 1·8 inches, and a triangle equal to $\frac{7}{8}$ths of the polygon.

16. Divide 5·4 inches so that the parts may be to each other in the proportion of the numbers 7, 8, 9, 11.

17. Two straight lines intersect at an angle of 35°, draw a circle of 2·25 inches radius touching both lines.

18. Inscribe an octagon in a square, the side of the square being 2·43 inches.

19. By means of the line of lines on the sector, from a line 4·37 inches long, cut off portions respectively equal to $\frac{3}{17}$ and $\frac{4}{19}$ of its length.

20. Draw an arc of 73° with a radius of 3·36 inches and one of 100° touching the former at one extremity, radius 2·5 inches.

21. By means of the lines of chords on the sector, draw an angle of 102°, and an arc of 2·25 inches radius, touching both lines containing the angle. Mark the points of contact of the arc and straight lines.

22. Describe a segment of a circle having a base of 2·36 inches and containing an angle of 115°.

23. A right-angled triangle has a base of 2 inches and an area of 2·58 square inches; construct it, and also one similar to it of half its area.

24. Draw a line 3 inches long, and from a point about 2 inches from it, and as nearly over one of its extremities as it can be placed by the eye, draw a perpendicular to it.

25. Construct an equilateral triangle 2·5 inches high.

26. Describe a circle of 1·85 inches diameter; assume a point 1·5 inches without it, and from this point draw a tangent to it.

27. Construct an octagon, with a scale of chords, on a line 9 inches long.

28. From a point A, the angles between points B and C, and C and D, were observed to be 40° and 50°; the lines joining B and C, and C and D being 1,200 and 1,500 yards, respectively and forming at C on the side nearest A, an angle of 155°. Find the point A. Scale—600 yards to an inch.

CHAPTER II.

CHAIN SURVEYING.

18. IT will simplify the following detailed explanations of the various methods of survey if the student will turn to *Plate* IX.; example of a chain survey, and imagine it to represent the real country. Then he will understand that if any straight line, such as *a*, *b*, *c*, *d*, be measured on the ground with a chain, and the distances of the various buildings, &c., &c., measured from it, as we come opposite each, and these measurements recorded in some convenient way in a book or on a rough sketch, then the exact *facsimile* of the country, with all the objects on it near that line, can be drawn to any scale we choose, and a plan prepared such as the example given; and to get in any extent of ground, we have only to measure more and more straight lines like those shown on the plan, passing near all the objects we wish to record the positions of, but we must also have some means of laying down these other lines, say, *al* and *dl* for example, in correct position with reference to the first line. Thus the survey consists simply in measuring first, straight lines all over the country and recording the measurements of the distances of the various objects from them, and secondly, the positions of the lines with respect to each other. For the first we merely require the measuring chain, for the second we may have an instrument which measures the angles, as *dal* and *adl*, or we may do it by only using the chain and measuring *al* and *dl*, and then constructing the traingle on base *ad*. We can now proceed to describe the various instruments and the methods of using them.

19. **The Flag.**—The first item is usually the ranging rod, *jhandi*, or bannerol as it is called in England. These should be made of straight light bamboo shod with iron at the bottom and provided with a conspicuously coloured flag, usually triangular, of about 1 foot sides. These rods are most convenient when made 10 feet long, coloured alternately black and white for each foot; they can then be used also as off set rods. When not in use these rods should be hung vertically to nails driven into a wall to preserve their straight lines, as it is not possible to range straight lines with crooked rods. *Jhandis* are used to mark out straight lines; when the line is short one may be placed at each end; but if the line is long intermediate ones are required: to place these the

surveyor stands exactly behind the flag at one end with his nose close to the bamboo, so, that he cannot see the bamboo at all, and looks straight at the flag at the other end; an assistant takes up an intermediate position holding a flag straight up, and moves to his right or left as directed by the surveyor, by lifting up either hand, not by shouting, till the flag exactly covers the one at the other end, when by a downward motion of both hands the surveyor notices to the assistant to fix the flag firmly in the ground. It often happens that straight lines have to be run in some convenient direction without a flag at the far end, but the process is very similar, two flags being fixed in the line, the assistant takes his flag beyond them, and is placed by the surveyor at the first flag, so that his is covered by the second, or indeed can place himself so that the two flags are covered one by the other from his position. The first flag can then be taken up and placed again in line with the two remaining ones further on. Khalassis who have had practice at this work, will run lines over all sorts of country, and even over villages, getting on the house tops, for miles with hardly any deviation from the straight.

20. **The measuring chain** is a lineal measure, constructed to suit convenience, of any arbitrary length, and divided into links, each link usually being the $\frac{1}{100}$th of the whole length.

For general use a chain of 100 feet, divided into 100 links of one foot each, is the most convenient; for work in the hills one 50 feet long may be used with advantage; but when the sole object is to obtain the acreage, *Gunter's chain* is specially adapted, for its length being 66 feet, or 4 perches, one square chain will represent 16 square perches. *i.e.*, the one-tenth of an acre. A Gunter's chain is also equal to 20 British metres of 39·6 inches. Gunter's chain divided by 11 is equal to 6 feet equals 2 fathoms. Gunter's chain divided by 12 is equal to 66 inches=double the Indian "gaz"=5′6″ which is the standard railway gauge for India. Again as Gunter's chain is the integral portion of a mile 10 square chains equal an acre and an inch of water on an acre weighs 100 British (Metric) tons nearly. Lastly a circle with a diameter of 7 yards has a circumference of one Gunter's chain assuming $\pi = \frac{22}{7}$.

The measuring chain is usually made of strong iron or steel wire, with a handle at each end, by which it is dragged along the ground. In the 100 feet chain each link is made up by a straight piece of wire about 10 inches long, and by one or more rings, which can be removed or more inserted at pleasure; these rings also form the connection between the links. To guide the eye in counting the number of links, brass marks

are fastened at the end of every tenth link, and distinguished from each other by notches, varying in number according to their position with respect to either extremity of the chain; so that the surveyor can, by simple inspection, readily read any required length. Steel chains are much to be preferred, as they are much stronger and lighter.

Accompanying the chain are 10 arrows, each about 15 inches long and made of iron wire; they are used in succession to mark the chain-lengths in measuring a line.

The chain is liable to many errors—first, in itself; second, in the method of using it; and, third, in the uncertainty of pitching the arrows. Every possible precaution must therefore be used.

If the chain be stretched too tight, the rings will give, the arrows incline, and the measured line will be shorter than it really is; on the other hand, if it be not drawn sufficiently tight, the measures obtained will be too long.

If the chain is a new one, it should invariably be measured *daily* until it has stretched to its utmost; if an old one, which a surveyor will find by experience to be always preferable, once in every three or four days may be sufficient. A careful and correct surveyor will, however, check it daily.

Chains have been known to stretch as much as three inches in a day's work; this, though trifling, in one chain, is of material consequence in a day's work of 200 or 300 chains; amounting, as such an error would, to about half a chain in the whole distance measured.

(*a*) *To check the length of a chain*, the ordinary levelling staff (*see* Chapter VI,) will for general purposes, be sufficiently accurate; two should be used in the following manner:—Stretch the chain moderately tight on a level piece of ground, fixing two stout wooden pegs at each end of the chain; one peg should be firmly driven and marked on the top with a fine tack or a hole made by the point of an arrow; then lay down the two rods from this end, and keeping the second stationary take up the first, place it beyond the second; then keeping that stationary, take up the second and place it beyond the third, until the end of the chain be reached, when the second peg may be driven and marked in the same manner at 100 feet or whatever length the chain is required to be. The chain should now be stretched between these two pegs, and its length corrected, if necessary, by adding or removing rings.

(*b*) *In using the chain* two men are required, one called the "forward" man who drags the chain forward, the other called the "chainman". The movements of the forward man are directed by the chainman; it devolves upon him to keep the forward man in the true line, to see that the chain is properly stretched, no kinks in it, &c. Before a line can be measured, its direction must first be clearly laid down by means of flags. A flag is placed upright at each end of the line, and if the line is very long, intermediate flags must be placed so that the chained line may not deviate from the line required. This is called "ranging" the line. In measuring the line the chainman stands at the starting flag and places his end of the chain in contact with it, while the forward man to whom all the 10 arrows have been given, proceeds with the other end of the chain in the desired direction until it becomes nearly extended. The forward man then squats on the ground, and the chainman directs him to one side or other till the arrow he holds upright in his right hand in contact with the outside of the chain handle is just on the far flag. A great deal of time is saved if the forward man is instructed to also align the chainman with the back flag, very often the forward flag is lost to view and then this is essential. The chain is now lifted partially from the ground, and the chainman seeing that it is in the right direction, gives the motion *down* to the forward man. The forward man then, keeping a firm pull on the chain, presses the arrow with his left hand firmly into the ground. They then proceed to the next chain-length, and so on.

The surveyor should keep a continual watch over the chainmen, and to do that his position must be just in rear of the chain. He must insist that the chainman brings his end of the chain up to the arrow in the ground, and that the forward man after getting in line and stretching the chain, puts his arrow firmly into the ground at the proper point. Strictly speaking a chain should be the thickness of one arrow less than its nominal length, otherwise the thickness of an arrow is gained in every measurement, which, when the distance measured is great, would amount to something considerable. If the ground is too hard to admit of the arrow being driven in, a cross should be scratched upon the ground, and the arrow laid down pointing to the intersection. In starting for a new length the forward man should give the chain a throw to one side so as to clear it from the arrow as it is dragged along.

After the forward man has fixed his last, the tenth arrow, he proceeds another chain's length; now, however, he has no more arrows

so immediately on getting into line and stretching the chain, he must put his foot on his end, or otherwise securely hold it, when the chainman brings up the arrows fixes one into position at the end of the chain and gives the balance of 9 arrows to the forward man to continue the measuring. The great objection to this arrangement is that during the exchange there is nothing in the ground marking the distance measured, and to remedy this some surveyors use eleven arrows, never taking into account the one arrow which is always in the ground at one or other end of the chain. But the eleventh arrow will creep into the tally unless the surveyor is constantly on the look-out; and consequently, attention to the arrows is added to the list of things to be kept in mind, whereas in the former case it is purely mechanical. Again, the mere act of changing calls the attention of the surveyor to the fact that another length of ten chains has been measured, and he notes it accordingly.

21. **Surveying by the chain only.**--This method of surveying is very slow but accurate, and is chiefly used for plans required on a large scale, such as maps of estates, &c., whose boundaries have to be carefully delineated. It is not suitable in a country where many obstacles impede the view or render horizontal measurement difficult. The plant required is very inexpensive,—a chain, an off-set rod and a few flag-poles being all that is necessary.

In making a survey with the chain only, we are confined to one, and the simplest geometrical figure, viz., the triangle; for of all plane geometrical figures, it is the only one * of which the form cannot be altered, if the sides remain constant. The surface to be measured is therefore to be divided into a series of triangles; and in this division it must be borne in mind that the triangles are to be as large, with reference to the whole surface to be measured, as is consistent with the nature of the ground; for, by such an arrangement, we are acting on the important principle in all surveying operations, that it is well always to work from *whole* to *part*, and not from *part* to *whole*.

The sides of these triangles are first measured, and as a necessary check on this part of the work, a straight line is in addition measured from one of the vertices to a point in or near the middle of the opposite side. This fourth line is called a tie line, and is an efficient means of detecting errors, if any have been committed in the measurement of the sides of the triangle. This fourth measurement is made in accordance with a maxim which ought invariably to be acted upon in all survey

---

* Euclid. I; 7.

operations, viz., that *where accuracy is aimed at, the dimensions of the main lines, and the positions of the most important objects, should be ascertained or tested by at least two processes independent one of the other.* Within the larger triangles, as many tie-lines and smaller triangles are to be measured as may be necessary to determine the position of all the objects embraced in the survey The directions of the lines forming the sides of these secondary triangles are so selected or disposed that they shall pass close by as many objects as possible, so that the off-sets to be measured from them may be as short and as few in number as practicable.

22. **Hand-sketch.**—The disposition and general combination of these triangles demanding care and judgement, it is customary, previous to commencing any measurement, to walk over the ground for the purpose of obtaining a general knowledge of the surface, and of the relative positions of the most conspicuous objects. The acquisition of this knowledge depending on the *coup d'œil*, is much assisted by an eye-sketch drawn with rapidity, and showing some of the principal roads, streams, temples, &c.

This hand-sketch is not drawn to any scale, and its object is attained if it simply bear a general resemblance to a plan of the ground, as it will thereby assist the memory in the distribution of the surface into triangles. It should invariably contain a North point, showing the direction of the meridian.

The method of finding direction of meridian by the sun's shadow is as follows.

Drive a stake having a pointed top, into the ground. Plumb it carefully so that it be quite vertical; mark where the sun's shadow is thrown, and with about that length as radius, describe upon the ground, with the stake as their common centre, two or three circles with slightly different radii. Watch the shadow of the top-point of the stake, and note where it touches the circumference of the larger circle, before noon and also after noon. Do this with the other circles; connect these points upon the circumference with the centre, and bisect the angles; these should have a common bisection. Should this not be the case, the mean may be safely taken provided the difference between them is not great. This bisector is the true North and South line: if now a compass be set up on the line and the bearing of a line read, that reading will be the variation of the compass at that point.

The hand-sketch, or rough diagram, is usually made in a Field-book, *i.e.*, a book in which every minute step of the operations gone through is

to be entered accurately in ink at the time. The after operations of plotting the survey from the Field-book are made very much simpler, if the positions of the measured lines and the stations be also shown in the rough sketch. Field books must be properly indexed with cross references when necessary. The index to appear in the first page of the book.

The sides of the larger triangles must pass as close as possible to the external boundaries to be surveyed; the triangles should, moreover, be made to approach, as nearly as praticable, to the equilateral form, avoiding with care very acute or very obtuse angles, because the further the form of the triangle is removed from the equilateral, the greater will be the alteration in the form of the figure and its area, should an error have been committed in the measurement of any one of the sides.

The triangles having thus been disposed to the greatest advantage, marks or pegs are placed in the ground at each vertex of the triangles; the general form or position is then noted on the hand-sketch previously made, and distinctive letters or numbers are written on the diagram at each point of intersection; this arrangement admits of easy reference in the Field-book, or on the ground, to any triangle or part of a triangle.

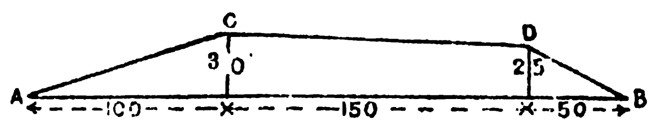
23. **Station points.**—The points of intersection of all straight lines, as well as the vertices of triangles, are always points measured *to* or *from*; they are called *station points*, and the lines connecting them, station lines, thereby distinguishing them from the simple off-set lines.

Whenever the station points occur along the various chain lines, a mark must be left in the ground at each station for future reference. In an extensive survey, the mark must be more or less permanent. In grass lands, a small peg driven into the ground at the station point, and surrounded or pointed at by some simple geometrical figure cut in the grass is sufficiently permanent; but in arable lands, there is no other way than driving in a good stout peg, and even that is liable to removal or to be ploughed up.

Stations are expressed in many different ways, either by letters or by the numerals, or by the numbers which represent the length of the line just measured. This last method, although often adopted by surveyors, is very confusing to the beginner; he should learn by lettering his stations, or if he thinks that he will have more stations than there are letters, let him use the numerals.

24. **Off-sets** are short perpendiculars, measured from a station line to the angles of a crooked or zigzag line near which the straight line runs, or to all objects which it is desired to represent on the plan.

Fig. 13.

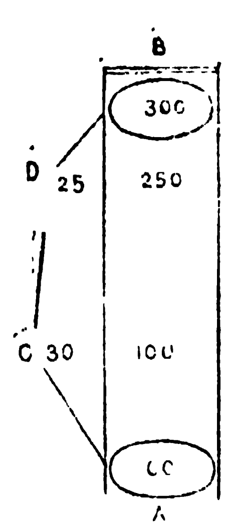


Thus, in the figure, let ACDB (*Fig.* 13) be a crooked fence bounding one side of a field. Chain along the straight line AB, which runs from one end of the fence to the other, and when opposite each corner, note the distance from the beginning, or the point A, and also measure and note the perpendicular distance of each corner C and D from the line.

The field notes corresponding to the above figure would be thus written (*Fig.* 14). The measurements along the chained line are written in the centre column, each one counting from the beginning of the line, and the off-sets are written beside them, on the right or left as the case may be, opposite the distance at which they are taken. A sketch of the crooked line is also added in the field-book.

These off-sets are usually measured by means of a rod, called an *off-set rod*, which is usually 10 links in length. When the objects are situated near the chain line it is easy to find from where the off-set springs, but when the off-set is of some length, say 80 or 100 feet long, it is not so easy to judge where the right angle would be. In such cases the eye is very much assisted by laying the off-set rod across the chain, as nearly at right angles as can be judged; if its prolongation does not pass through the object, it must be shifted along the chain until it does. A second trial will always be sufficient to find the exact place. But all Volunteers can stand square on the chain and look to their front, and right or left close, till they find the object direct in front.

Fig. 14.



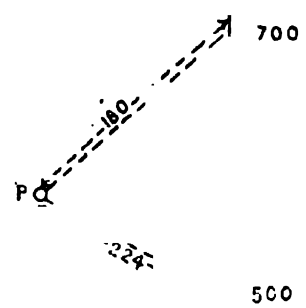
Off-sets must be taken sufficiently often to ensure the accurate plotting of the work on paper, but a little consideration will often obviate much unnecessary work and reduce to a minimum the number of off-sets whose measurement is actually required. For instance, in running a chain line along or near a made road, it is quite unnecessary to read off-sets to both sides of the road and also to the hedges and ditches which may bound the road; it is quite sufficient to read an off-set to the side or centre of the road, and only occassionally measure the width of the road with the corresponding distances to its bounding hedges and ditches, unless marked changes in the widths occur. Again, the number of off-sets is largely dependent on the scale to which the survey is to be plotted; if, therefore, the scale of the plan is too small to admit of roads or drains, &c., to be shown, except by

the conventional signs in use, it is useless to take off-sets except to the centre of the road or drain.

Off-sets longer than 100 to 150 feet should never be admitted in a chain survey having any pretensions to accuracy. The lines to be chained must be so adapted that no such long off-set will be necessary, or, if the main lines cannot be changed, smaller triangles must be built on them, and so prevent the necessity of long off-sets.

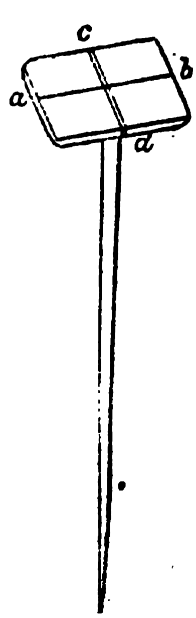
If the position of a solitary object is required, and it is too far to admit of an off-set to be taken to it, its position can be accurately determined thus:—Suppose P (*Fig.* 15) is some isolated object, and it is opposite some point 600 in the chain line, and about 2 chains distant. When the arrow denoting 500 has been fixed, measure the distance from the arrow to the object P, and enter it as shown in the diagram. Then continue chaining the original line until the 700 arrow is fixed, then again measure the distance from the arrow at 700 to P, and enter it in a similar manner. The point P can now be accurately placed on paper with reference to the chained line. Care should be taken that P should form the apex of a triangle as nearly equilateral as the eye can judge.

Fig. 15.



(*l*) **Cross staff.**—An instrument called the "*Cross staff*" (*Fig.* 16), which can be made up by any bazar carpenter, is sometimes used for the purpose of taking off-sets. It consists of a piece of wood, about 6 inches square and an inch-and-a-half in thickness, fixed on the end of a staff about 5 feet in length, with an iron spike at the end for the convenience of planting it in the ground. The square piece on the top has two grooves *ab* and *cd* in it, about half an inch deep, at right angles with each other, made with a common saw. This instrument being placed any where on the chain line, if one groove be directed to the forward or back station, the other will of course give the perpendicular to the chain line. The "*optical square*" is the better instrument for such work where great accuracy is essential, and it is used a great deal by the "*patwaris*" of villages in making out the areas of fields for revenue purposes. As these both

Fig. 16.



have to be shifted along the line like the Volunteer, they are most laborious to use, and if the rule of keeping to short off-sets is adhered to, the eye is a sufficiently accurate guide.

25. THE FIELD-BOOK should be of a convenient size for the pocket, having each page ruled with a central column, which is about $\frac{5}{8}$ths to one inch in breadth. The entries are always made commencing at the bottom of the page, the surveyor walking along the line looking at the front flag, as then the page becomes a small, though distorted, representation of the reality. Were the entries made from the top downwards, the Field-book would then represent the reverse of the reality.

In keeping the Field-book, it should ever be remembered that the central column is virtually but *one* line representing the chain, the space within the column being merely required for the several distances on the chain, whence the off-sets are taken; and also, that all off-sets read either way *outwards* from the centre column, in the same way as they have measured *outwards* from the chain; if the station line, therefore, should be crossed on the ground by a road or any boundary meeting it obliquely, its representation in the Field-book must not be made to pass obliquely across the middle column, but must arrive at one side of the column and leave it at the other, at points precisely opposite, as it would do were the middle column merely the thickness of a line: inattention in this particular, causes much confusion in the relative position of off-sets.

The entries must be made in ink and corrections must be made in ink initialled and dated. The pages should also be numbered for facility of reference, headed with the name of the lines of which the page contains the survey, and each day's work dated. Names, numbers, figures etc., can be neatly entered in the style shown in Plate IV *a*.

In a Field-book it is a saving of labour to call each combination of two pages, as it lies open, one page.

The Field-book should contain no erasures of any kind. Should it be necessary to correct an entry, it must be done by drawing the pen through the original entry, and writing the correction above it.

Writing down the chainage, *i.e.*, the distance measured, in the central column of the Field-book, is at first a little puzzling. The surveyor should always enquire from the chainman the number of arrows he has in his hand to find out the distance, he should never ask the forwardman unless it be to satisfy himself that none of the arrows have been dropped. Suppose that an off-set 25 feet long, falls on the 50 mark of the first chain measured, then in the central column 50 is written, and to the

right or left, as the case may be, the off-set 25 is placed. Let another off-set fall at 47 links on the chain, the chainman holding 6 arrows in his hand, the chainage will then read 647 ; after the first change of arrows, say that the line crosses a ditch at 79, the "chainman" holding 3 arrows, the chainage then will be 1379 ; if this had occurred after the 5th change, the chainage would have been 5379, and so on ; hence the necessity of entering the chainage each time a change of arrows occurs, as it denotes that 1000 links or 10 chains have been measured ; if this is neglected, a length of 10 chains is very apt to be left out, and particularly so when few off-sets are taken. When chaining very long lines, it is advisable to enter each 1000 links in brackets, thus—(1), (2), (3), and make the off-set entries in hundreds and feet only.

The usual error beginners make is to write too small figures and close together, plenty of room should be taken. When off-sets are to be taken to a complicated object, say the building at top of example of Field-book, it should be sketched in first, and the distances written in afterwards, opposite its points : there is no object in having the distance entries at even distances on the paper. This is done in all but the first page of the example to save space in printing. The first page is the real specimen. Another point to which the attention of beginners is directed is, that they should carefully consider by what off-sets the position of a house or any feature of ground can be most accurately determined. For example, in the case of the large pucka house at the top of page 1 of the example, the off-sets 129 and 93 from points 320 and 404 of the chain line are much more important than the off-sets 93 and 118 from points 404 and 412. The important off-sets of any particular feature can only be determined by careful consideration and practice.

Figures denoting dimensions of details of plans of buildings should be used as sparingly as possible, and should invariably be included between arrow heads as in draughtman's work, to prevent their being confused with figures denoting off-sets, which latter should always be written close against the points to which they refer, and not midway between the point and the chain line.

No Field-book is complete unless it contains at the beginning of the work an index showing on what pages the detailed survey of any particular line may be found.

26. Scale of Plan.—Before commencing the actual measurements in the field, the scale of the plan, or in other words, the degree of accuracy, should be considered. The $\frac{1}{100}$th of an inch is about the smallest length

that can be shown on paper, so if the scale is to be 100 feet to an inch or larger, the chainage and off-sets must be read accurately to the nearest foot; whereas if the scale was to be 500 feet to an inch, no distance under 5 feet in length would be perceptible on the plan. These considerations determine the number of off-sets required, for the larger the scale, the greater the detail that can be shown.

It cannot be too strongly impressed on the surveyor that the work which he is called upon to perform depends for its accuracy in a very great measure on the order, system and neatness bestowed on all the steps, whether of delineation or measurement: proper attention in keeping the Field-book saves much time in plotting, and guards against the errors unavoidably arising from reference to a confused Field-book, moreover, care bestowed in the first essays, will amply reward the surveyor, by giving accuracy of eye, freedom and steadiness of hand; qualities indispensable to his success.

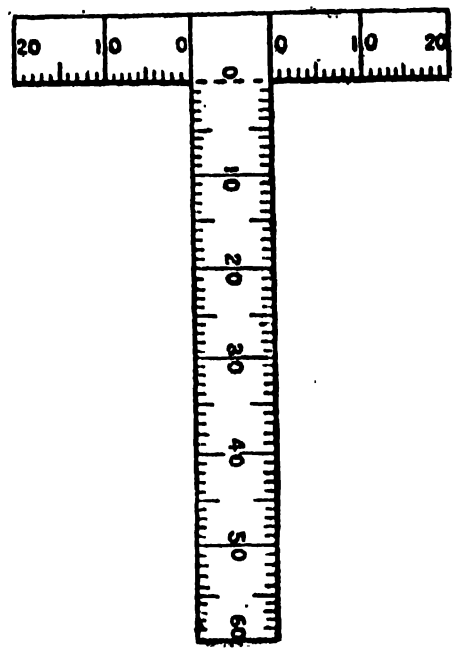
27. **Specimen of Field-book and Plan.**—A specimen is here given of a Field-book, *Plate* VIII., and the plan made from it, as an example of a chain survey, *Plate* IX. The ground was walked over first of all, and a rough sketch was made showing nearly the position of the river, its two bridges, the village, jhil, church, &c. This gave a good idea as to the disposition of the necessary lines which would have to be measured.

The line *a*, *d*, *g*, was first measured, and off-sets taken to everything which was required to be shown on the plan; *b*, *c*, *d*, *e* and *f*, were intermediate stations left on the line from which to run cros or tie-lines, or else from which to fix on other triangles. Then the lines *dl* and *la* were measured, and *h* and *k* in the former and *m* in the latter were left as intermediate stations; then the cross lines *ch*, *bk*, *mt*, were chained to enable off-sets to be taken to the objects in the middle of the triangle, and also to serve as check lines when plotting the survey.

The cross lines may be left until the sides of all the principal triangles are measured, and then each triangle may be filled in afterwards, but the points in the main line from which it is intended to run them must be marked at the time of measuring the sides of the principal triangles, or a great deal of unnecesssary measurement will be entailed. Thus are all the sides of triangles measured in succession, and their dimensions with the additional assistance of the off-sets, give the means of ascertaining all the boundaries, external and internal, positions of houses, &c., and of finding the area of the whole and of every part, by direct computation from the Field-book.

28. **Plotting the Survey.**—The method of plotting a chain survey is so self-evident, that a few words of explanation will suffice. In the above example, lay down on paper a line equal to *ad*, taken from any scale of equal parts from the same scale take the length *al* with a pair of compasses, and with this as a radius and *a* as a centre, describe an arc; now, taking *ld* as a radius and *d* as a centre, describe an arc, cutting the first, their intersection wil give station *l*. In the same way lay down the triangles *lna* and *adv*. Now commence with *ad*, and mark off the distances given in the centre column of the Field-book, at the same time setting off the off-sets; for this purpose a small cardboard or paper scale, of the shape shown in *Fig.* 17, will be found very useful; by means of the middle scale either of the short arms can be placed at the required distance from the station and the off-sets marked off from them. In the same way proceed with the sides *al* and *dl*, and then fill in the triangle by means of the cross lines *ch* and *bk*. Proceed with the other triangles in a similar manner until the whole is completed.

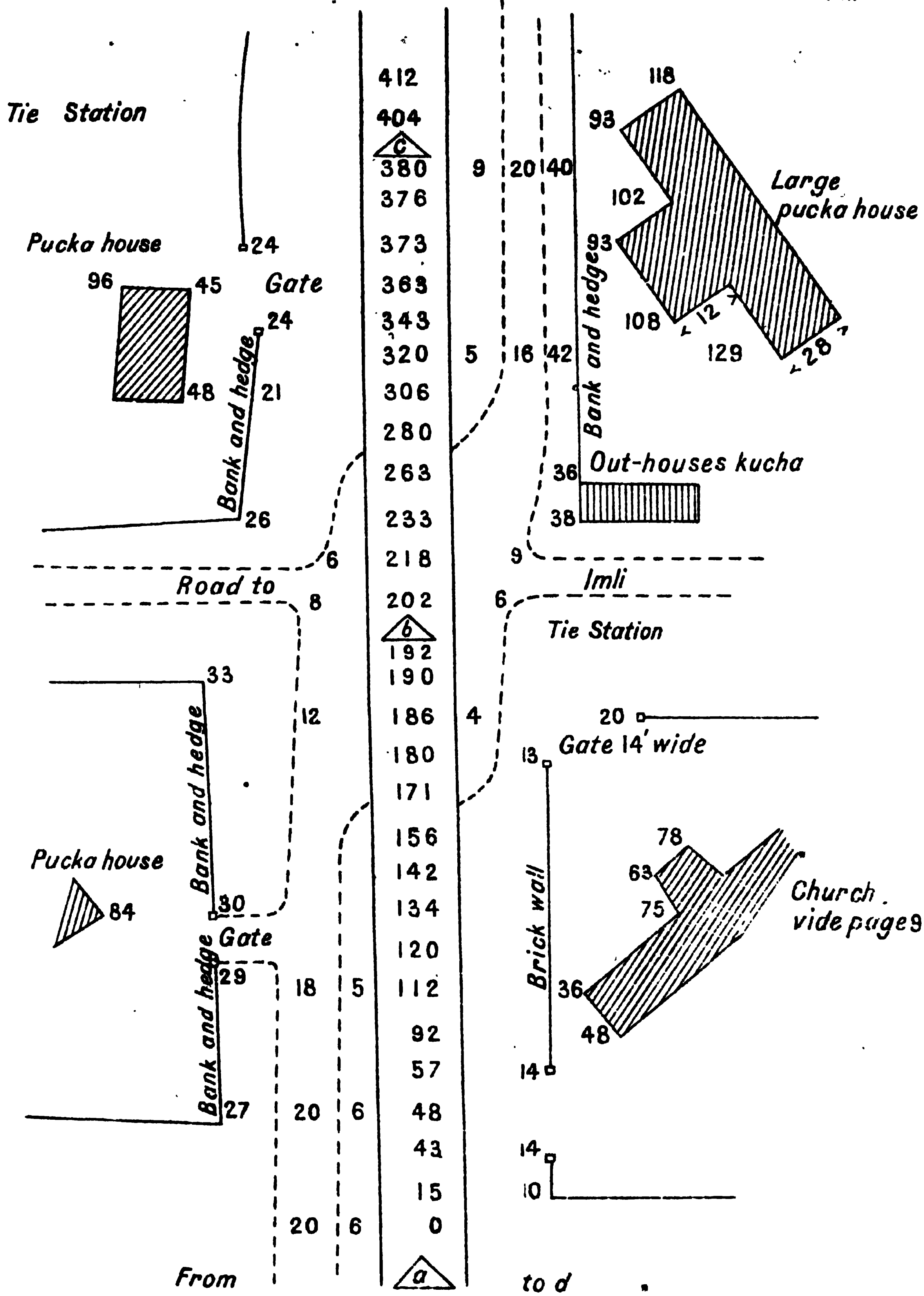
Fig 17.



When using engineer's scales and off-sets the scales should be so placed parallel to the main line and even pinned down with two drawing pins placed over its extremities so that the centre line of the off-set will slide correctly along the main line. This is the most effective way of using the engineer's plotting scales.

29. **Learning Survey.**—It is an excellent way to commence with to take any plan, and treat it as real ground; lay down and measure lines on it, and off-sets from them to the objects shown, and make out a complete Field-book from it. Then putting away the plan, plot the Field-book on a fresh sheet of paper, and compare result with original. The student can rectify omissions in Field-book and learn the routine very easily this way, and will start on the actual survey with more confidence. He should also learn where great care is necessary as in chaining main lines, and where approximations can be safely made as in taking off-sets to unimportant buildings or to features of ground the outlines of which are not clearly defined Also bear in mind that the Field-book should always be made out in such a way as to allow of its being plotted by some different person who had never been over the ground surveyed. To this

PLATE VIII.

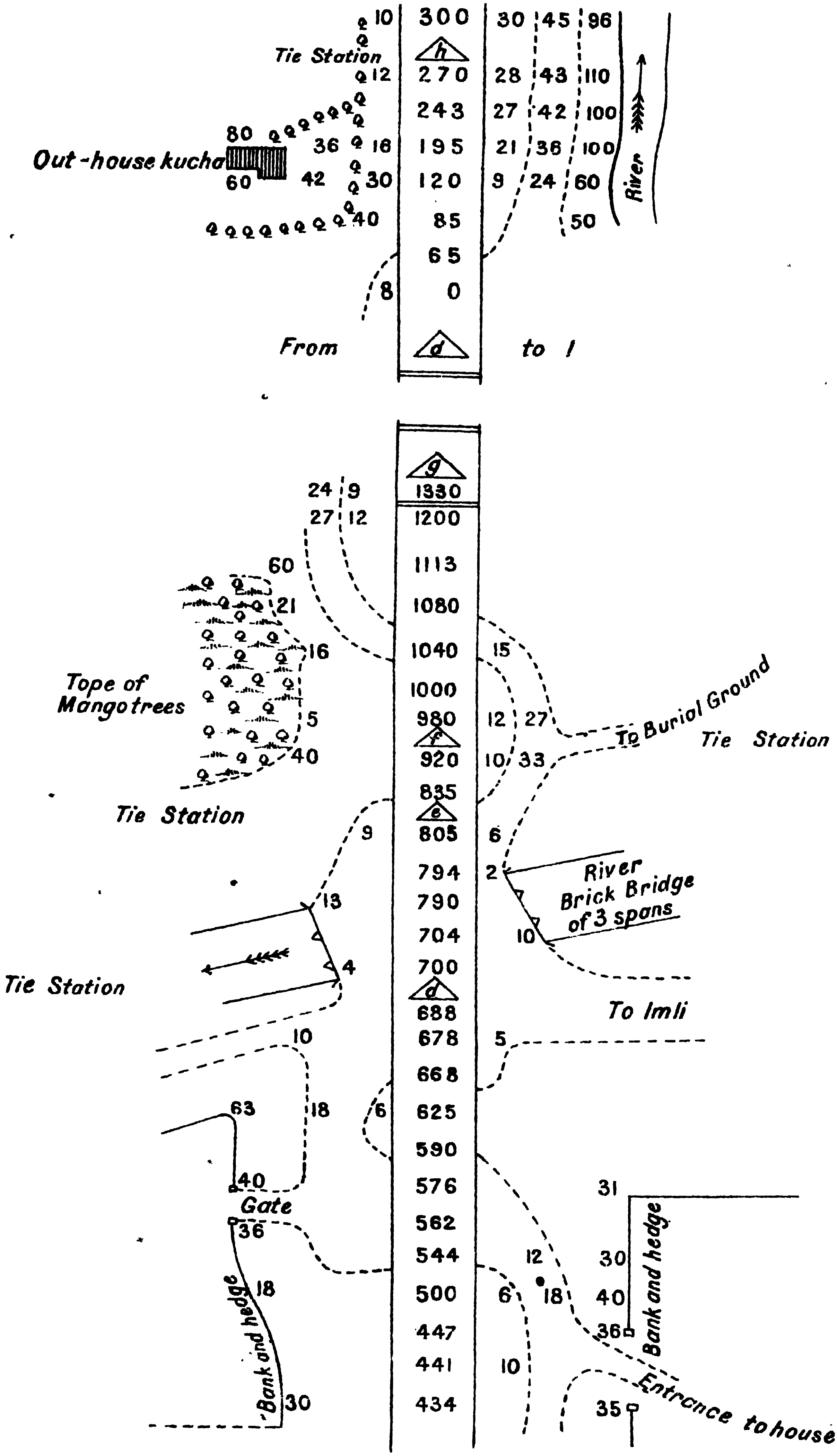


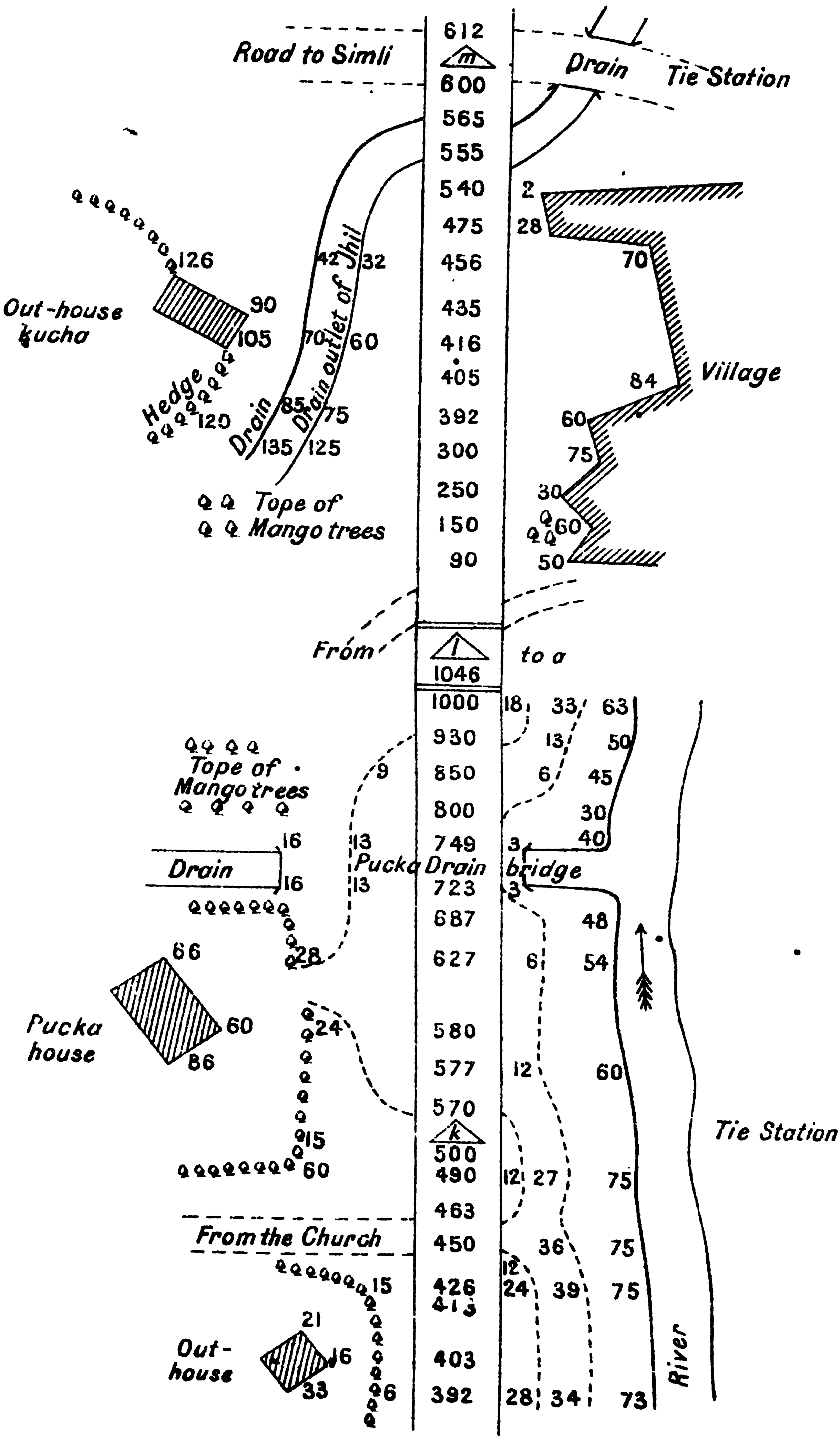
From △ a go North-East
Commenced at Drain Bridge, S. W. corner of Church
August 19th, 1865. Chain 100 feet long.
Tindal, Ganga.

Scale-100 Feet to an inch.

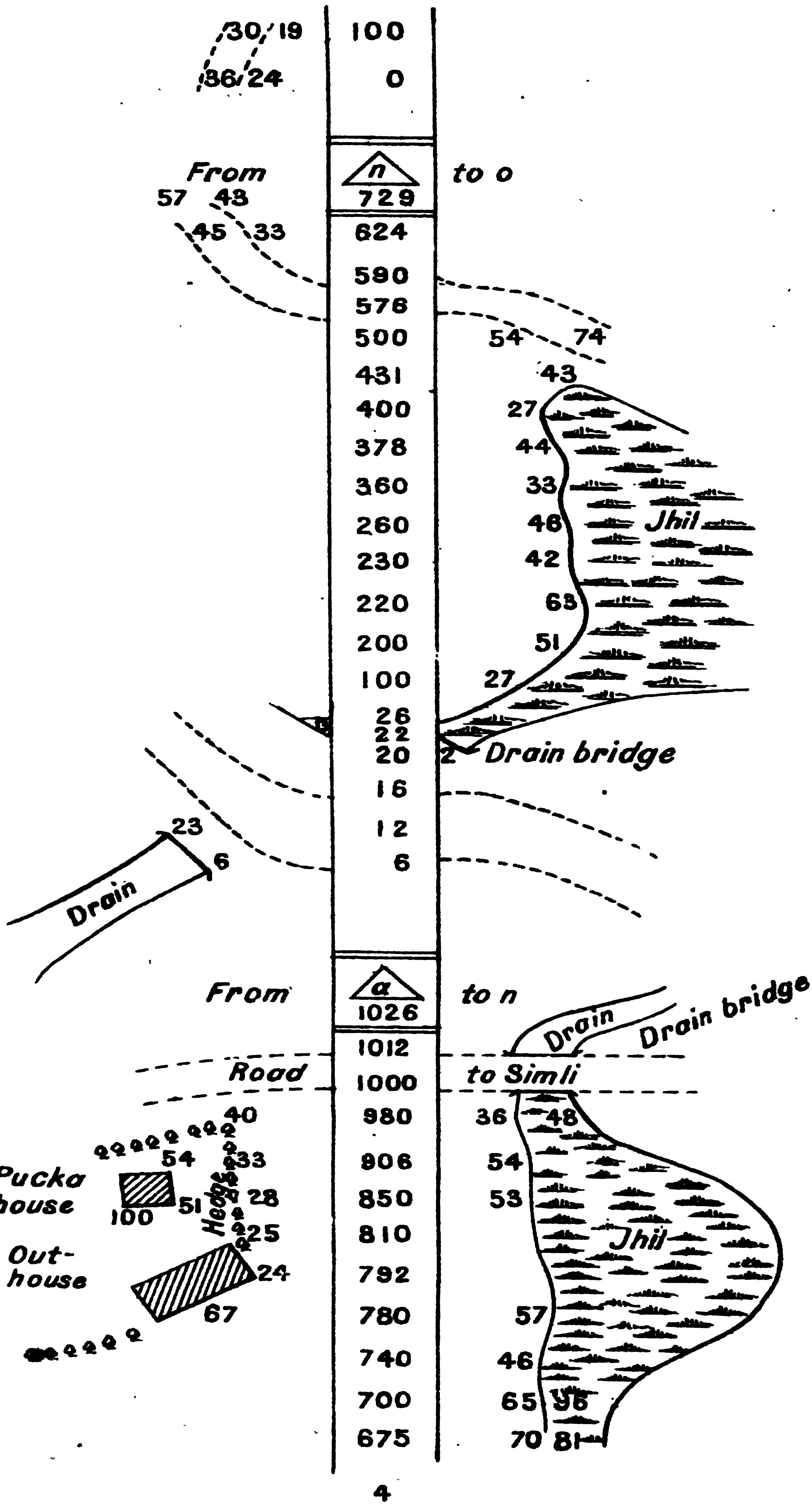
FIELD-BOOK OF A CHAIN SURVEY.

No. 1496-10

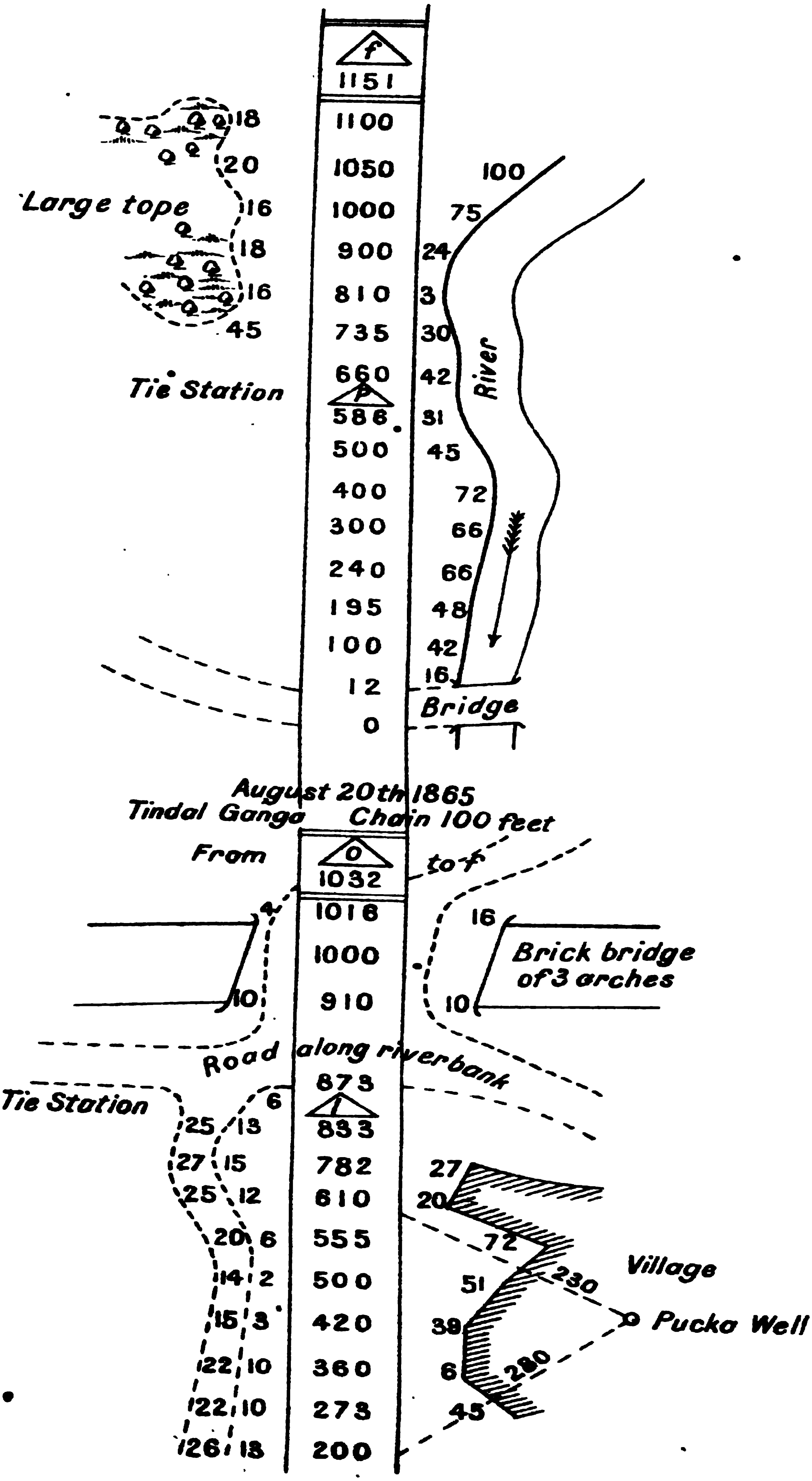

300
Tie Station
270
243
195
120
85
65
0
Out-house kucha
River
From
to I
1330
1200
1113
1080
1040
1000
980
920
835
805
794
790
704
700
688
678
668
625
590
576
562
544
500
447
441
434
Tope of Mangotrees
Tie Station
To Burial Ground
Tie Station
River Brick Bridge of 3 spans
Tie Station
To Imli
Gate
Bank and hedge
Bank and hedge
Entrance to house

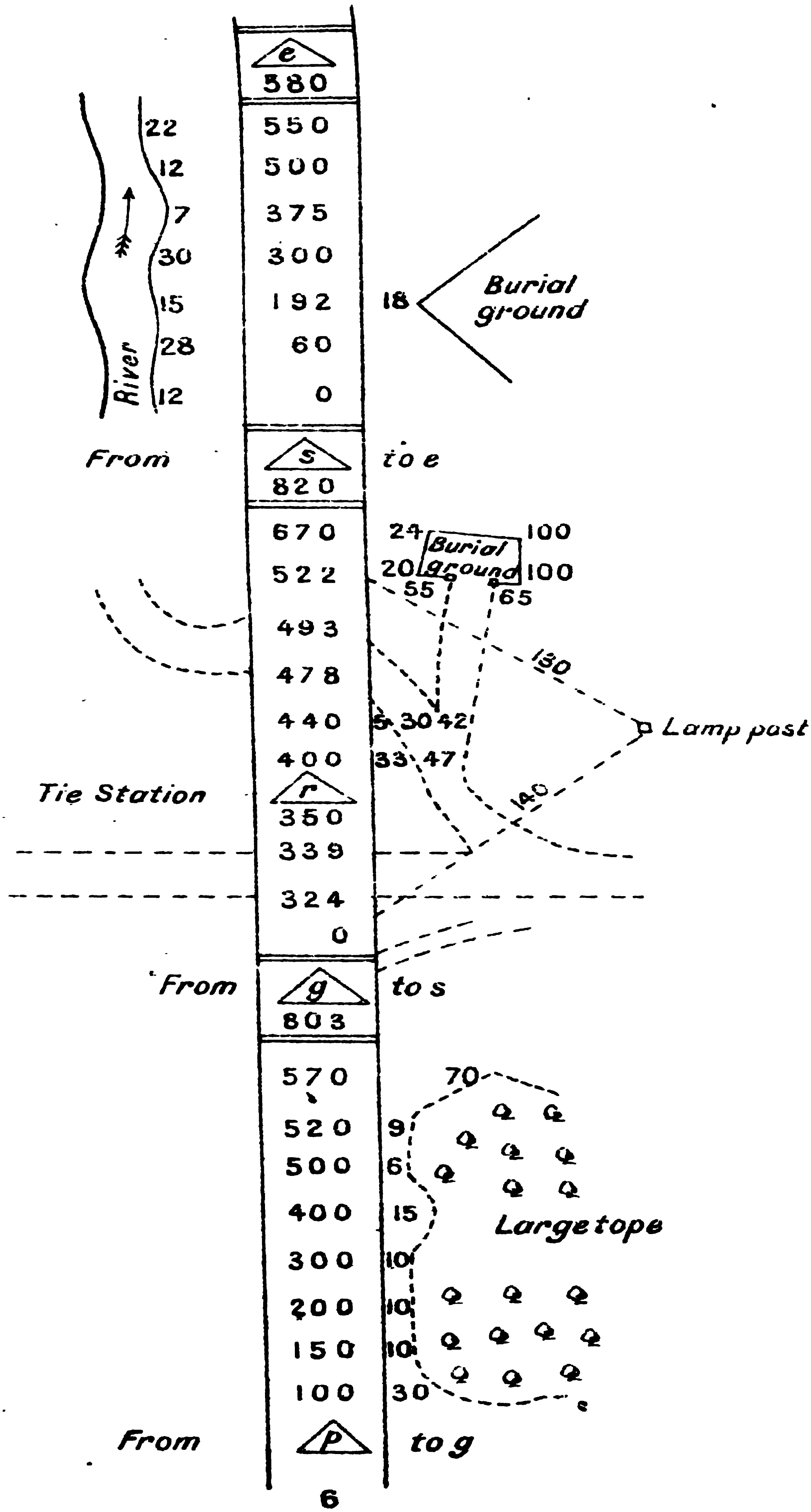

Road to Simli
Drain
Tie Station
Out-house kucha
Drain outlet of Jhil
Drain
Hedge
Village
Tope of Mango trees
From
to a
Tope of Mango trees
Drain
Pucka Drain bridge
Pucka house
Tie Station
From the Church
Out-house
River

3

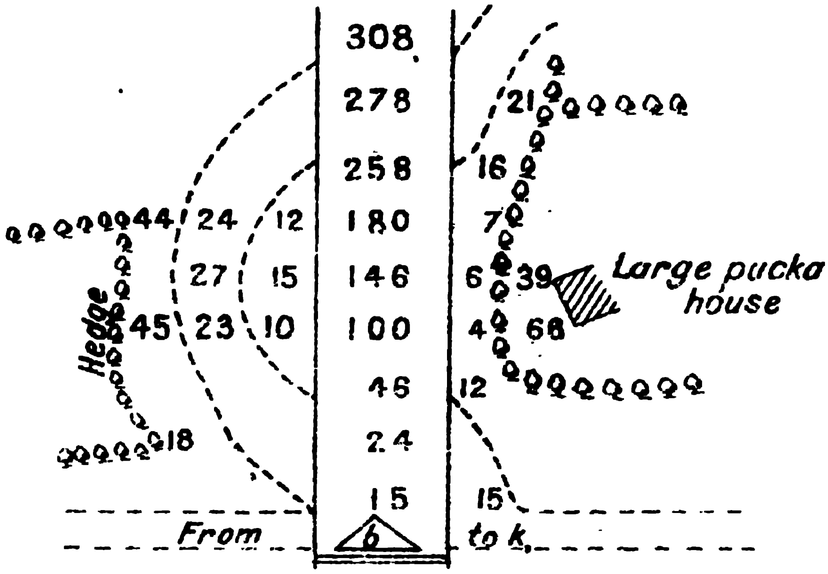


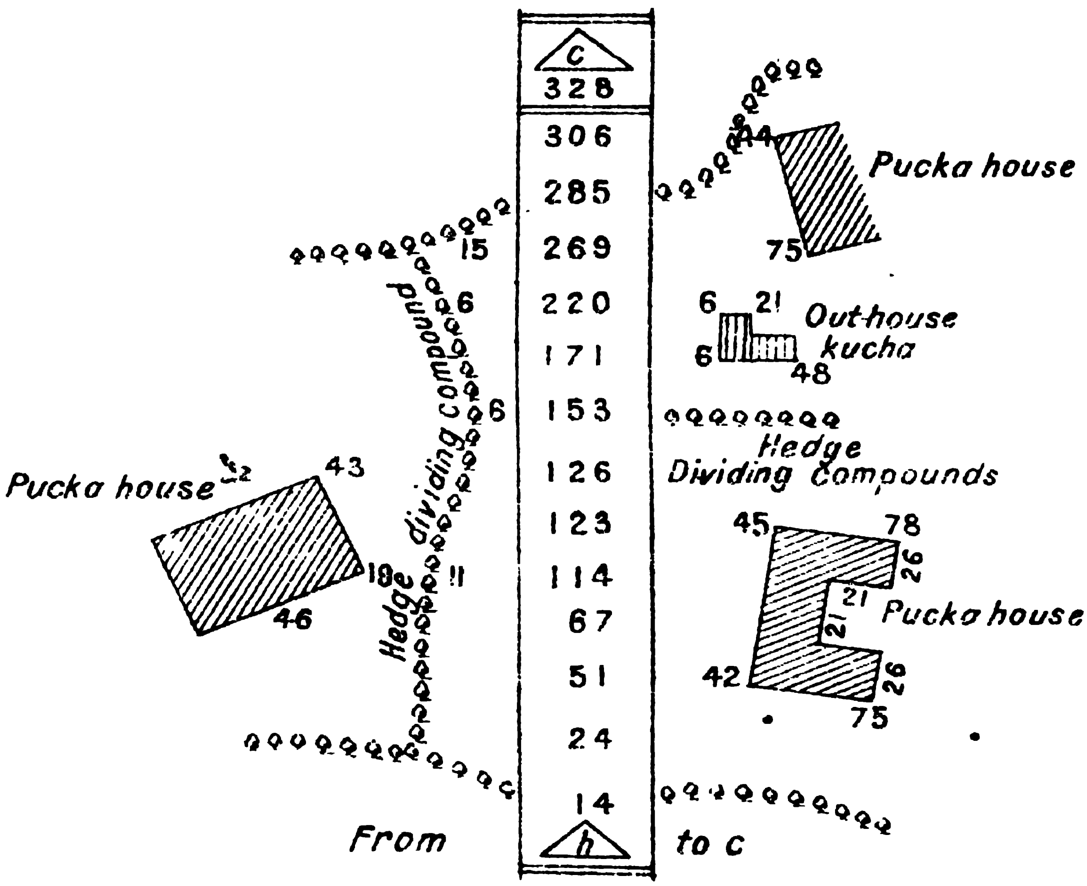
30 19
36 24
100
0
From
n
729
to o
57 48
45 33
624
590
576
500
54 74
431
43
400
27
378
44
360
33
260
46
Jhil
230
42
220
63
200
51
100
27
26
22
20
2
Drain bridge
16
12
23
6
6
Drain
From
a
1026
to n
Drain
Drain bridge
1012
Road
1000
to Simli
980
40
36 48
Pucka house
906
54
33
54
850
51
28
53
100
Hedge
810
25
Jhil
Out-house
792
24
67
780
57
740
46
700
65 96
675
70 81

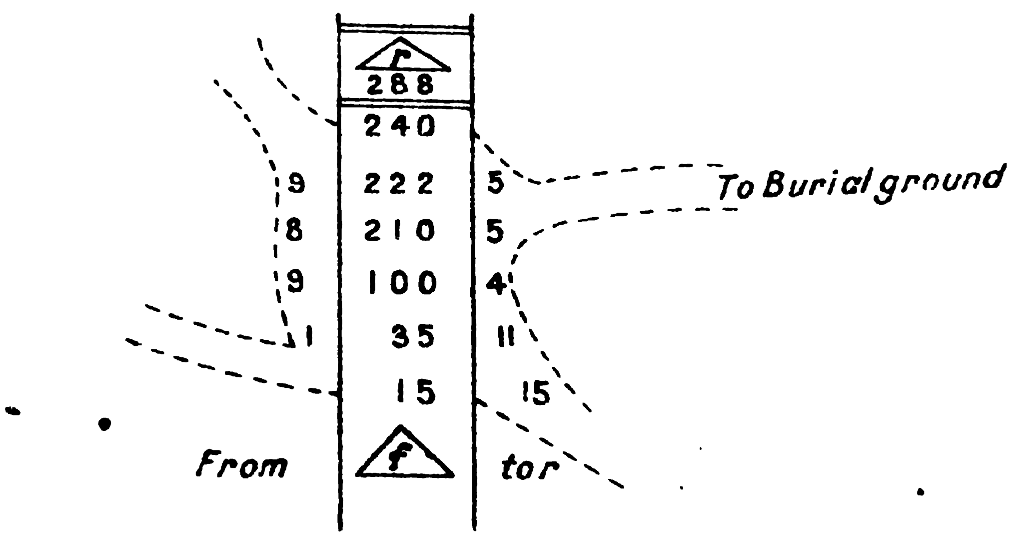

f
1151
1100
1050
1000
900
810
735
660
p
586
500
400
300
240
195
100
12
0
18
20
Large tope
16
18
16
45
Tie Station
100
75
24
3
30
River
42
31
45
72
66
66
48
42
16
Bridge
August 20th 1865
Tindal Ganga
Chain 100 feet
From
o
to f
1032
1016
1000
910
4
10
16
10
Brick bridge
of 3 arches
Road along riverbank
873
6
Tie Station
1
833
25 13
27 15
25 12
20 6
14 2
15 3
22 10
22 10
26 13
782
610
555
500
420
360
273
200
27
20
72
51
39
6
45
230
280
Village
Pucka Well

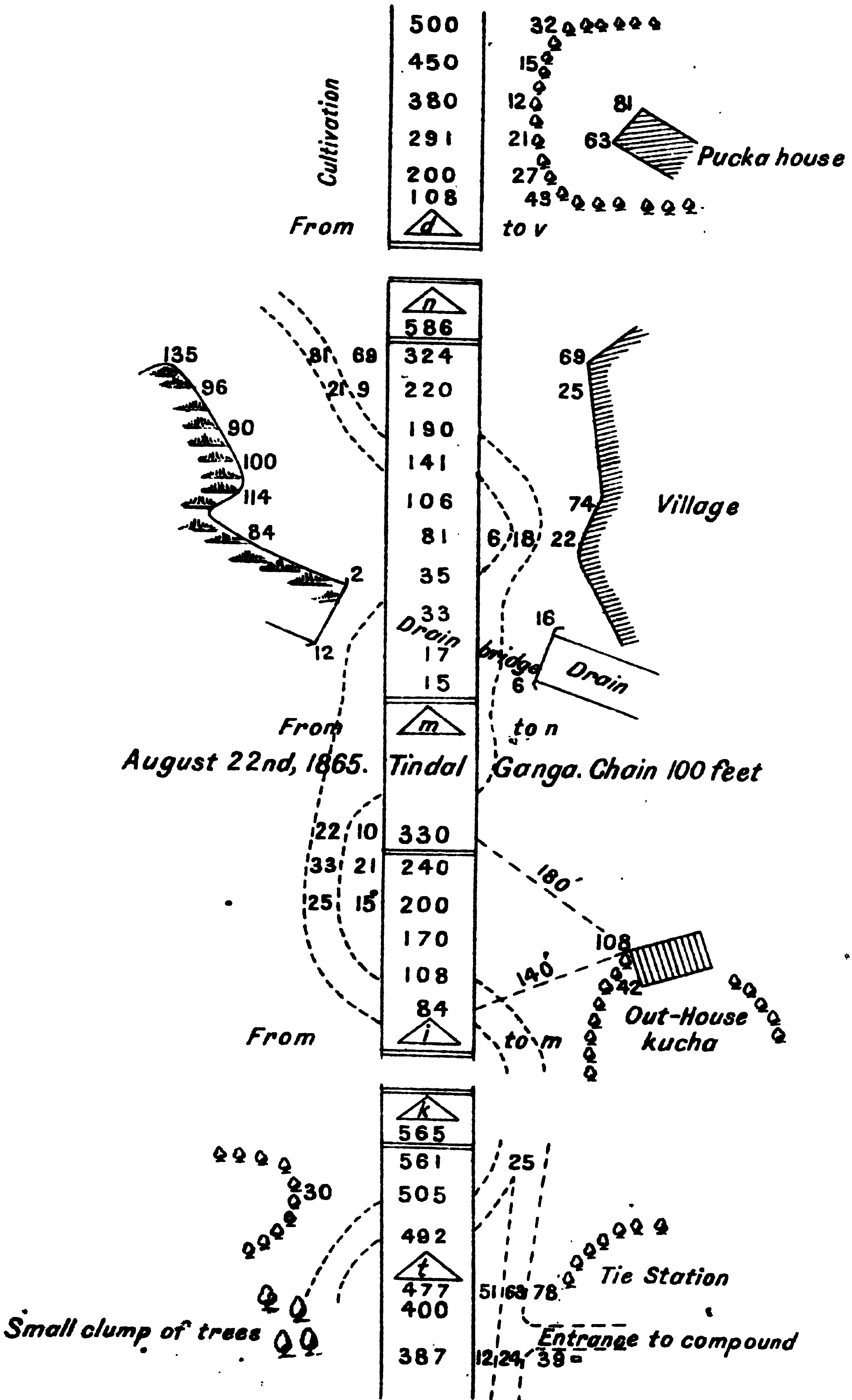


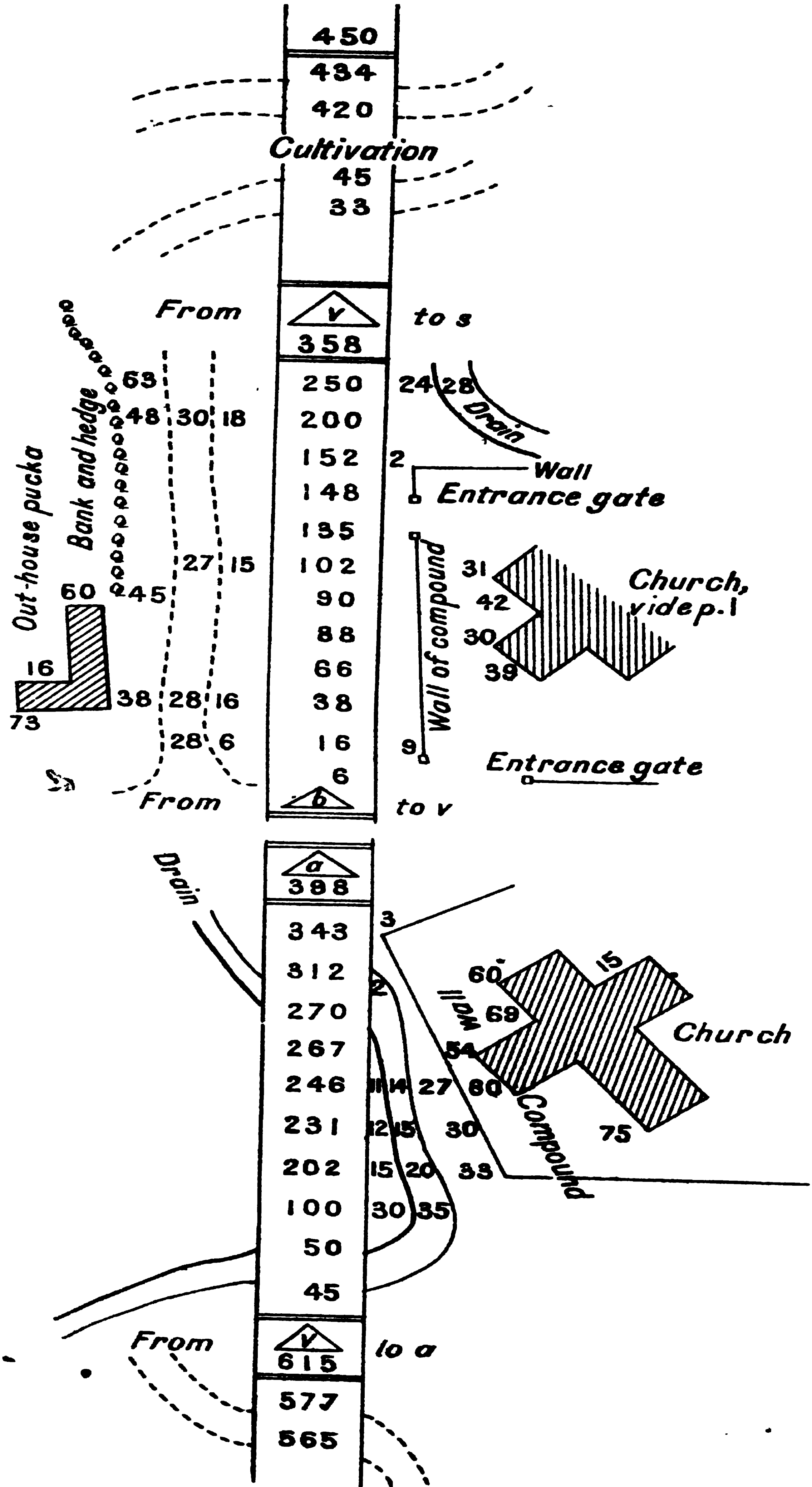
e
580
550
500
375
300
192
60
0
22
12
7
30
15
28
12
River
18
Burial ground
From
s
to e
820
670
522
493
478
440
400
24
20
100
100
Burial ground
55
165
130
Lamp post
5
30
42
33
47
140
Tie Station
r
350
339
324
0
From
g
to s
803
570
520
500
400
300
200
150
100
70
9
6
15
10
10
10
30
Large tope
From
P
to g
6

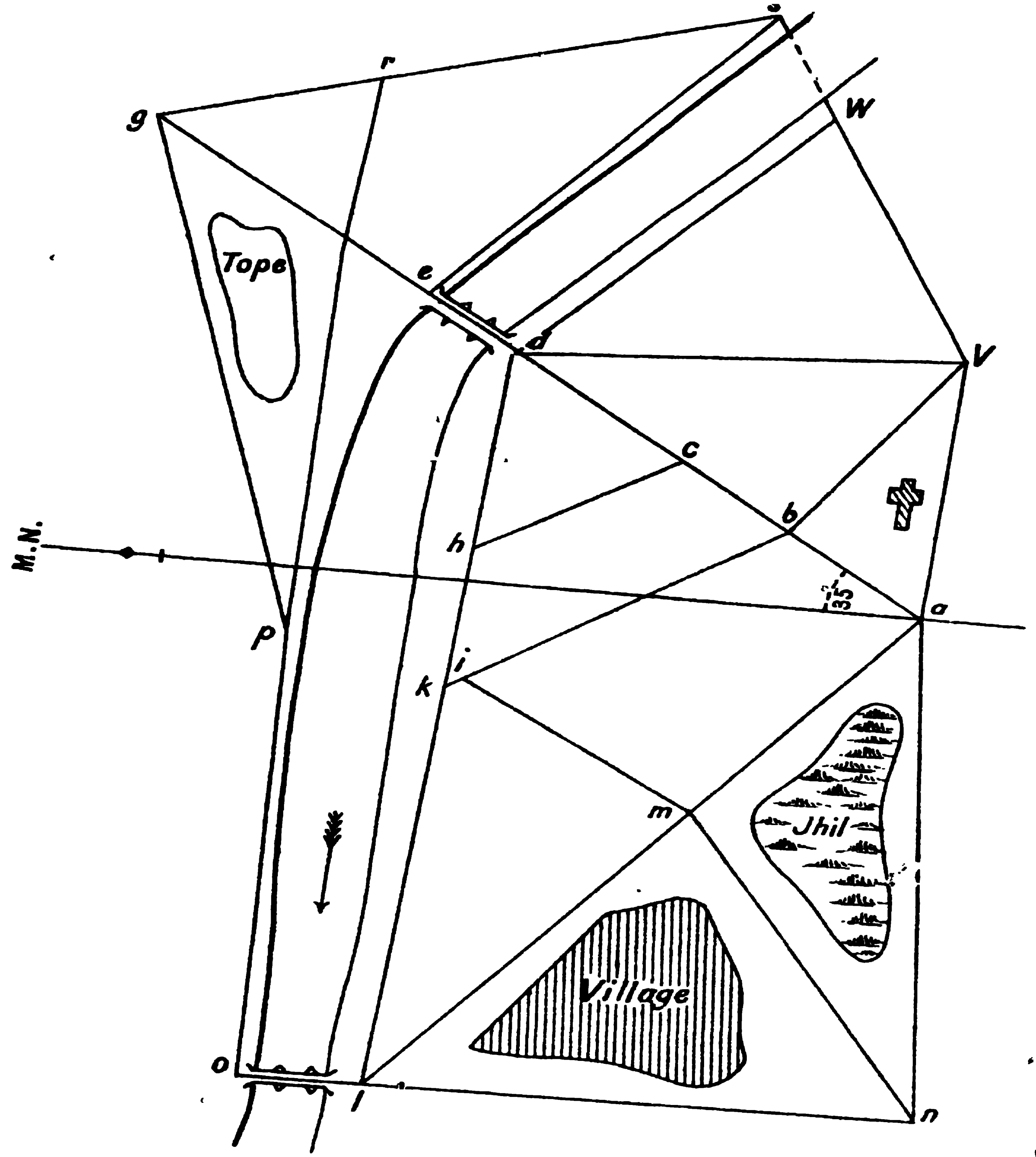

308
278
258
180
146
100
46
24
15
21
16
7
6 39
4 68
12
15
44 24 12
27 15
45 23 10
18
Hedge
Large pucka house
From
b
to k.


c
328
306
285
269
220
171
153
126
123
114
67
51
24
14
44
Pucka house
75
6 21
Out-house kucha
6 48
Hedge Dividing Compounds
45 78
26
21
21
Pucka house
42 26
75
15
6
6
11
Hedge dividing compound
Pucka house
43
19
46
From
h
to c


r
288
240
222
210
100
35
15
9 5
8 5
9 4
1 11
15
To Burial ground
From
f
to r

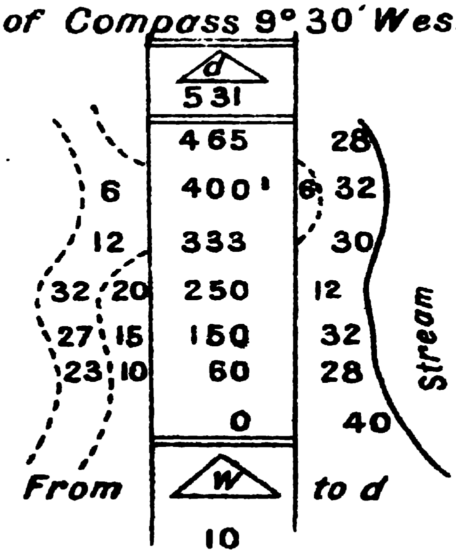

500
450
380
291
200
108
Cultivation
32
15
12
21
27
43
81
63
Pucka house
From
d
to v
n
586
324
220
190
141
106
81
35
33
Drain
17
15
135
96
90
100
114
84
2
12
81
69
21
9
6
18
22
69
25
74
Village
16
bridge
6
Drain
From
m
to n
August 22nd, 1865.
Tindal
Ganga. Chain 100 feet
330
240
200
170
108
84
22
10
33
21
25
15
180
140
108
42
Out-House
kucha
From
i
to m
k
565
561
505
492
t
477
400
387
30
25
Tie Station
51
63
78
Small clump of trees
Entrance to compound
12
24
38


450
434
420
Cultivation
45
33
From
v
to s
358
250
200
152
148
135
102
90
88
66
38
16
6
b
From
to v
24
28
Drain
2
Wall
Entrance gate
Wall of compound
31
42
30
39
Church, vide p. 1
9
Entrance gate
Out-house pucka
Bank and hedge
63
48
30
18
27
15
45
60
16
38
28
16
73
28
6
a
398
Drain
343
312
270
267
246
231
202
100
50
45
3
2
11
14
27
12
15
30
15
20
33
30
35
Wall
60
15
69
54
80
Church
Compound
75
From
v
to a
615
577
565



Rough Sketch in Field-Book, showing the positions of the measured lines, and the various stations.

The line adg bears 35° from Magnetic North
Variation of Compass 9° 30′ West of North



end the hand-sketch referred to on page 48 and the index referred to on page 53 should never be omitted, and cross-references should be made wherever possible, *i.e.*, should any house or feature of ground or station occurring in a page of a Field-book have occurred previously in a former page, cross references to the two pages should be made. It is only by a constant regard to clearness and conciseness that the isolated field observations of the surveyor can be knit into an accurate whole.

CHAPTER III.

THE PRISMATIC AND SURVEYING COMPASSES.

30. **Bearings and Angles.**—Before proceeding to describe the methods of Surveying with 'angular instruments,' it is as well to understand at first the difference between *bearings* and *angles*. Euclid's definition of an angle is, "the inclination of two lines to one another;" the prismatic compass, however, does not show this inclination, but only shows how the line from the object to the observer is inclined, or *bears* to the magnetic meridian. Therefore, to find the angle subtended at the observer's eye between two objects with the prismatic compass or Surveyor's compass, it is necessary first to find the *bearings* of the two objects, *i.e.*, the angles they make with the magnetic meridian, and take the difference between these two readings, to get the angle: this will hereafter be shown. The Pocket Sextant and the Theodolite read these angles directly.

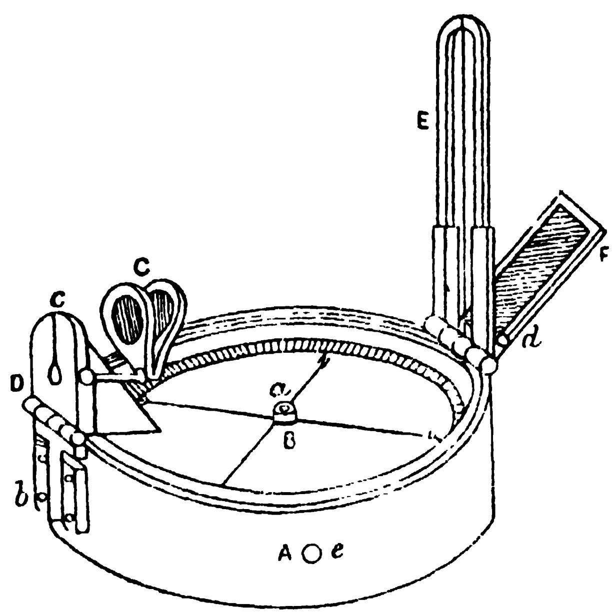
Horizontal angles between the geographical meridian and lines from observed objects to the observer are known as *azimuths*, or sometimes "true bearings." Azimuths are inclinations from true North (or South) and are therefore to do with the earth's centre. Bearings are inclinations to some certain adopted meridian as in traversing and thus are to do with the earth's surface. Inclinations from magnetic North should invariably be called *magnetic* bearings and not simply bearings.

31. **Prismatic Compass.**—By the aid of the Prismatic Compass horizontal angles can be measured to within about one quarter of a degree. It is particularly useful in filling in the details of a survey, for sketching along a road, or river, or any continuous line of military works; in fact in the hands of the civil or military engineer it is an invaluable little instrument. The compass is often held in the hand when the bearing of any object is taken, but much greater accuracy can be obtained by placing it on a stand.

In the figure (*Fig.* 18), A represents the brass compass box with a fine steel point in the centre at *a*, B is a circular card, or in better instruments, a fine circular rim of aluminium, in either case graduated all round from 0° to 360°. On the line 0° to 180° is fixed the magnetic needle, having at its centre a little agate cap, which fits on the steel point *a*, and leaves the needle and card free to revolve, so that when at rest the zero line of the graduated circle will always point north.

The magnetic needle should be powerful and at least 4 inches long; the circumference of the card is usually divided in degrees and half degrees. This ultimate division is quite small enough, as the eye can judge any further sub-division with sufficient accuracy.

Fig. 18.



The bearing of any line or object is found by turning the compass box gently, till looking through the slit *c* in the sight D, the vertical thread of the sight-vane E coincides with it. The card itself remains stationary with its zero line due north, and therefore the figure under the prism which appears by reflection to coincide with the sight thread is the bearing of the object.

The prism *c* through which the observer looks in using the instrument, is mounted with a hinge-joint D, by which it can be turned over the side of the compass box, that being its position when put into the case. Owing to the prism being placed at the reverse side of the graduated ring, and also that everything seen through it is inverted, the zero of the ring is placed at the *south*, and the numbers of the graduations *reversed* and written upside down; by this means the number seen through the prism is the reading required. The sight-vane has a fine thread or horse hair stretched along its opening, in the direction of its length, which is brought to bisect any object, by turning the box round horizontally, the vane also turns upon a hinge-joint, and can be laid flat upon the box, for the convenience of carriage. F is a mirror, made to slide on or off the sight-vane E; and it may be reversed at pleasure, that is, turned face downwards: it can also be inclined at any angle by means of its joint *d*; and it will remain stationary on any part of the vane by the friction of its slides. Its use is to reflect the image of an object to the eye of the observer when the object is much above or below the horizontal plane. When the instrument is employed in observing the azimuth of the sun, a dark glass must be interposed, and the colored glasses represented at C are intended for that purpose; the joint upon which they act allowing them to be turned down over the sloping side of the prism-box.

At *e* is shown a spring, which being pressed by the finger at the time of observation, and then released, checks the vibrations of the card, and brings it more speedily to rest. A stop is likewise fixed at the other side of the box, by which the needle may be thrown off its centre; which

should always be done when the instrument is not in use, as the constant playing of the needle would wear the point upon which it is balanced, and upon the fineness of the point much of the accuracy of the instrument depends. This stop is now generally placed close to the hinge joint of the sight-vane E, and is so arranged that the mere act of laying the sight-vane flat on the glass face, throws the needle off the pivot. A cover is adapted to the box, and the whole is packed in a leather case, which may be carried in the pocket without inconvenience.

Prismatic compasses* are now very generally made with a silver graduated circular rim, which is merely affixed to the magnetic needle, and the card dispensed with. By this means the sensitiveness of the instrument is much increased, as the whole of the weight resting on the pivot is removed as far as possible from the centre. The silver rim should not be less than 4 inches in diameter. This ring, when weighted and the instrument held in a vertical plane, enables vertical angles being read and the instrument is thus also a clinometer.

Method of use.—The method of using the instrument is very simple. First raise the prism in its socket *b*, until you obtain a distinct vision of the divisions on the card, and standing at the place where the angles are to be taken, hold the instrument to the eye, and looking through the slit *c*, turn round till the thread in the sight-vane bisects one of the objects whose 'relative inclination' or angular distance from any other object is required; then by gently touching the spring *e*, check the vibration of the needle, if necessary, and when it has finally come to rest, the division on the card which coincides with the thread on the vane, will be the 'magnetic bearing,' or inclination of the object from the North point of the magnetic meridian. Then turn to any other object and repeat the operation; the difference between the bearing of the object and that of the former, will be the angular distance of the objects in question. Suppose the former bearing to be 40° 30′ and the latter 10° 15′, both read from the North point, then the angle will be 40° 30′—10° 15′=30° 15′.

The divisions in some instruments are numbered from 0° to 180° south counting eastward, and thence to 180° north counting westward others are numbered 5°, 15°, &c., round the circle to 360°, 90° representing east, 180° south, 270° West and 360° north. These latter are by far the best, as the least liable to error in recording the results in a Field-book and are more generally understood by Indians.

* A prismatic compass can be adjusted to read a certain inclimation to north by shifting the magnetised bar underneath the disc or ring.

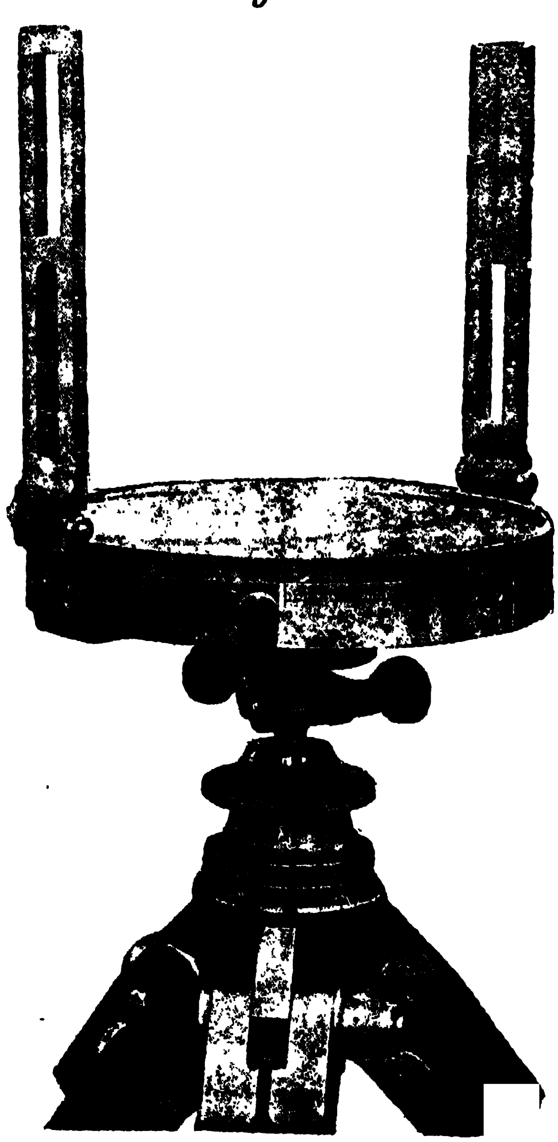
This instrument must be held or set up as nearly horizontal as possible in order that the card may play freely; also it must not be used near iron, or by a surveyor wearing steel rimmed spectacles.

The meridian line given by any magnetic needle differs from the "true" or "geographical" meridian by an amount which is known as the magnetic variation. The compass variation will generally be found to differ slightly in different compasses, although nearly alike for compasses used in the same district. The slight difference is due to the zero line of the compass card not coinciding exactly with the axis of the magnetic needle. In order that the work of several survey parties may be successfully combined, however, it is necessary that the "variation" of each compass be known and allowance made for it in plotting bearings.

Variation is said to be east or west according as the magnetic meridian lies to the east or the west of the geographical meridian, and methods of finding its amount are given in Chapter IV, Part II.

32.—**The Surveying Compass.**—The surveying compass consists of a compass-box, magnetic needle, and two plain sights perpendicular to the meridian line in the box, one of which has a longitudinal slit through which the surveyor lines the horse hair on the object of which the bearing is required; it is used for the same purpose as the prismatic compass, for filling in the interior detail of a survey by means of bearings, but is so inferior to that instrument that surveyors now never use it.

Fig. 19.



There is one peculiarity connected with this instrument and, indeed, with all compasses in which the magnetic needle swings freely over a fixed card, that the east and west points of the horizon appear to have changed places. In the prismatic compass the graduated arc is attached to the needle, and conseqently is always stationary; the bearing of any object

therefore is the same angle as that through which the *sights* have moved from the meridian. In the surveying compass, the card and sights are fixed and so move together, the bearing of any object then is the same angle as that through which the *card* has moved. For instance, say an object bears 90° east; that is at once read off by the prismatic compass, but in the surveying compass the north point of the card is now pointing towards the object, and the west point of the card is now under the north point of the needle.

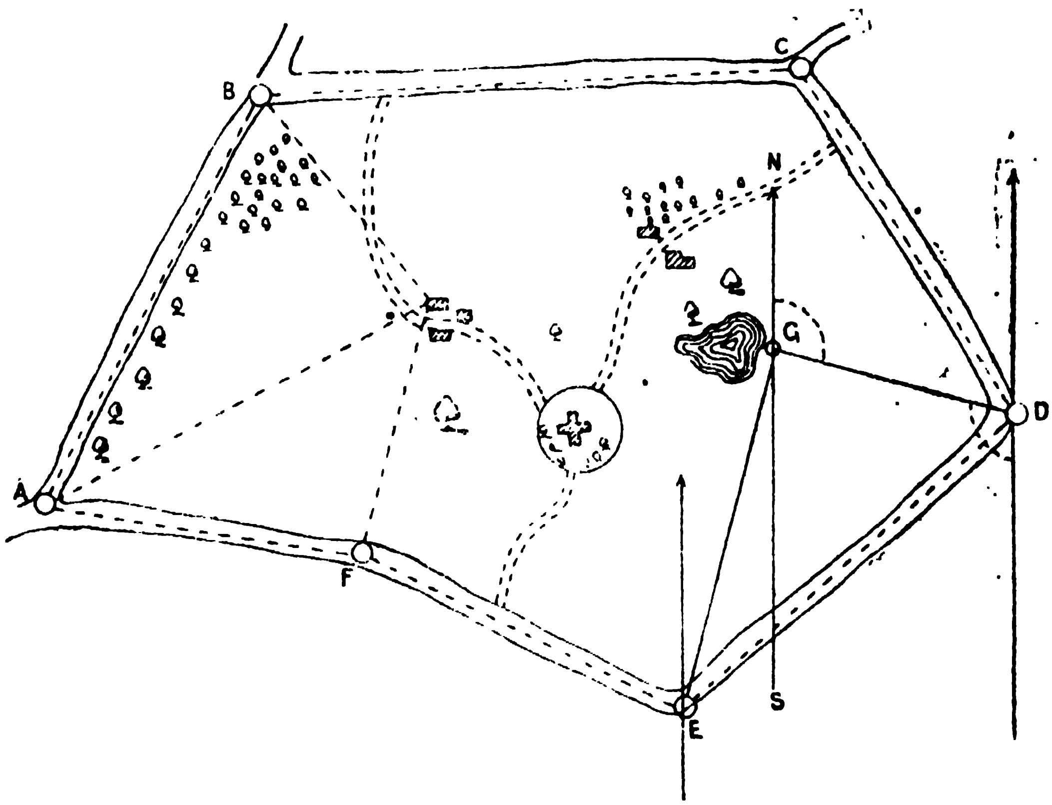
The reason for changing the position of the words now is obvious; for were they not changed, the observer would read the bearing as 90° *West* (seeing the word west under the needle), thus reading a bearing diametrically opposed to the reality.

33. **Method of Surveying with the Prismatic or Surveying Compass.**—This only differs from that described for chain surveying in that the bearings of the straight lines from which off-sets to the various objects are taken can now be measured, and, therefore these can be plotted from the north line, and there is no necessity for cutting up the survey into triangles as before. Also bearings can be taken from two or three points to distant objects, as the block of buildings in the example, which is fixed by the intersection of bearings from A, B and F, and thus the necessity of running a line near enough to it to take off-sets is avoided.

Let the annexed plan (*Fig.* 20) represent a survey of roads to be performed by the prismatic or surveying compass. All preliminaries of making a hand sketch. and selecting stations for a chain survey having been completed set up the compass at A, and send a man with a flag-staff to B. Now take the bearing of B, and proceed to chain from A to B, taking off-sets to the sides of the road and any remarkable objects, precisely as in a chain survey. Having arrived at B, the compass must be again set up, and a flag-staff having been sent to C, its bearing must be obtained; then the line BC is to be measured, and so on. Bearings must also be taken to any conspicuous objects that are out of reach of an off-set, such as the corner of the house in the figure; readings from two points are sufficient to fix it but a third should be taken as a check.

Surveying with the compass is more convenient where the ground to be surveyed is a large open tract with a few isolated important features, or where long straight lines and convenient ties or triangles cannot be made on account of obstructions, but it is more liable to error, as the compass is often sluggish and the needle does not swing exactly to the true north, and, therefore, care should be taken to check the work by measured

Fig. 20.



cross ties as much as possible to avoid having to do the detail work over again.

When surveying a large area, the main framework of lines, as sketch, *Plate* IX., should be entrusted to the most experienced or accurate worker of the party, inferior men can then fill in the details between the points so fixed, and this main framework should be plotted to avoid possible waste of labour.

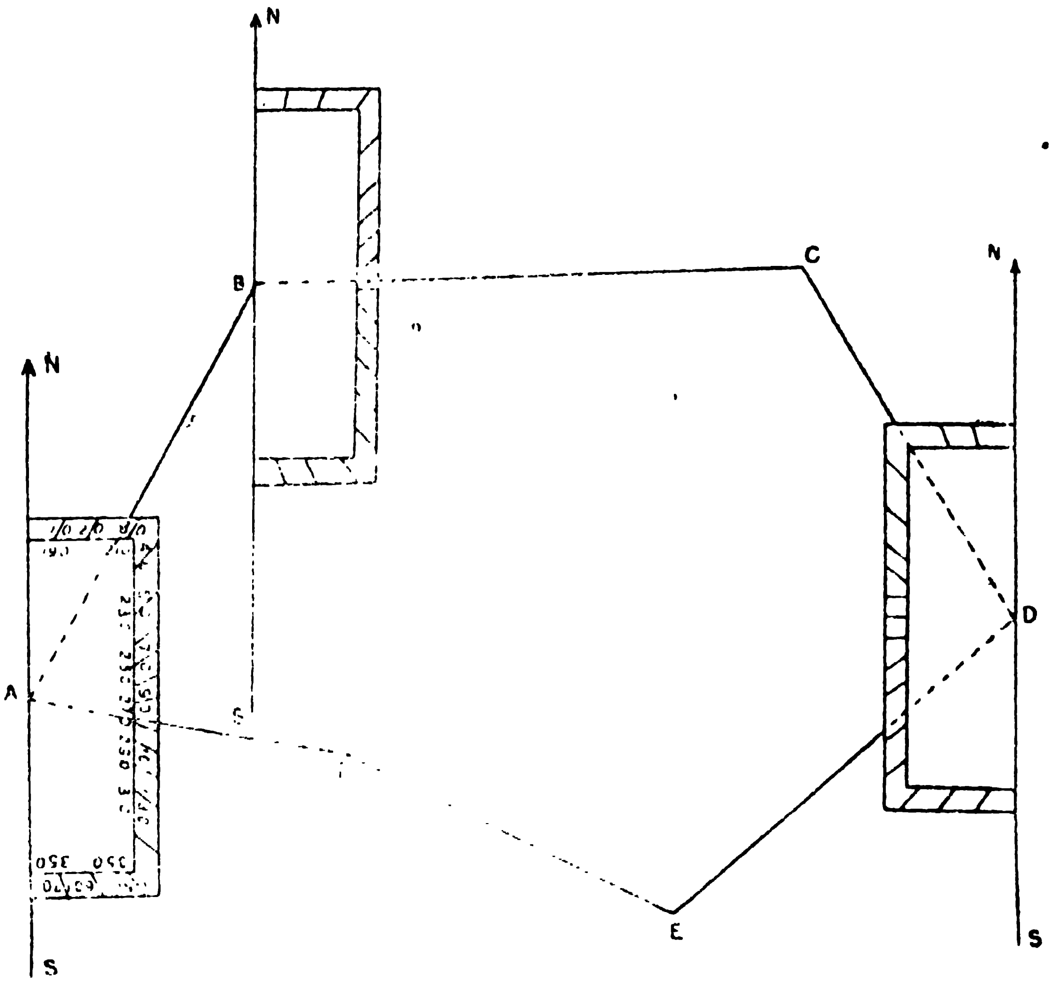
34. **Chain and Compass Survey.**—Where the area to be surveyed is covered with close detail, which it is required to plot to a large scale, as in the case of a cantonment or town, a combination of both chain and compass survey is generally the most suitable rapid method by which it can be carried out. The ground should first be gone over with a view to choosing the positions on the main circuit as in compass survey, and a hand-sketch made as described in para. 22. It should then be noted on the hand-sketch what tie-lines, run between points on the main circuit, will sub-divide the area most conveniently. These secondary stations on the main circuit are known as tie-line stations, and it will probably be necessary to run minor tie-lines between points on these main tie-lines until the whole of the detail is brought within reach of the off-set rod. This form of survey differs from the ordinary Chain Survey described in para. 21 only in the fact of it not being absolutely necessary to work in triangles, but it should be borne in mind in this as in all other

survey work that the triangle is the only safe figure to work with, as it is the only one whose sides do not admit of distortion when their lengths are known, and whenever possible the work should be carried out in triangles. It will be found to save confusion if the stations of the main circuit be denoted by Roman capital letters, the primary tie-line stations by italic letters, and the minor tie-stations by numerals.

35. **The Field-book** is kept as in the chain survey, the only addition being the bearings. The bearing to the next forward station is called the "forward bearing;" this should be written in the centre column immediately above station No. 1. It is only *necessary* to take bearings from every other station—for instance, we might go to B, (*Fig.* 20), and from there observe the bearings of both BA and BC, then to D, and observe DC and DE; but it is advisable to take readings at every station, for it prevents confusion in the field-book, and also the trouble of adding or subtracting 180° from every second reading, which in the other case would be necessary before the work could be plotted. To ensure accuracy and to check the vagaries of an indifferent compass, or to detect errors in reading, it is always well to read both the *forward* and *back* bearings at each station. The previous "forward" and the new "back" bearing should differ by 180°; if the divergence is slight, i.e., up to one-quarter degree, the mean should be used, but if great, the work cannot be depended upon, as the compass must be out of order, else one of the bearings must have been read incorrectly.

36. **To plot the above Survey** (*Fig.* 21).—Having fixed on a convenient spot on the paper for the starting point A (i.e., so that the survey may be contained in the paper, and as nearly in the middle as possible), draw a line through it to represent the magnetic meridian, place the protractor to the right of this line, the edge coinciding with it, and the centre at the point A; now, with a pencil mark the required angle, and draw a line through this point and A, this will represent the first bearing; on this line, produced if necessary, set off from any scale of equal parts, the length of AB, and through B draw the line NBS parallel to NAS to represent another meridian, and placing the protractor as before, lay off the angle NBC; set off BC the required length; and proceed with each angle in the same way until the end of the line FA should coincide with the starting point A. If an angle greater than 180° is required to be set off, the protractor must be placed to the left of the meridian, as at D, and the second row of figures used. In projecting the circuit, in order to get good results, the longest setting by the protractor on the given meridian is advisable. Having completed

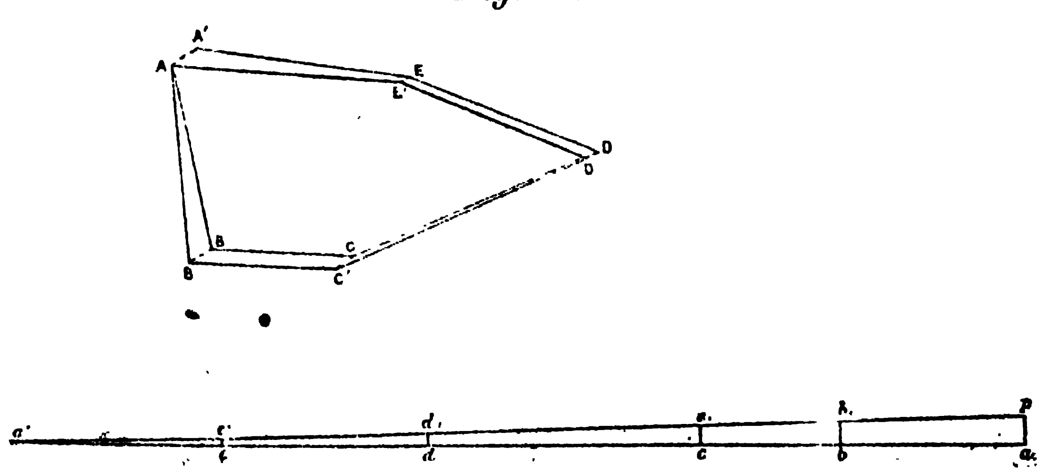
Fig. 21.



the circuit and corrected it if necessary (see next paragraph) the off-sets can then be plotted in the same manner as in the chain survey.

37. In plotting a chain survey by means of protractors it is impossible to get the angles perfectly accurate. Not only this but with a prismatic compass absolute accuracy is unattainable and in plotting work of this nature we shall as a rule find a closing error i.e., the circuit as shown on the plan will not close. To adjust the error all round the survey the following method is used :—

Fig. 22.



Suppose a traverse A B C D E A has to be plotted (Fig. 22) and on completing the circuit we find that the last line EA falls as shown by EA' in the above figure thus not closing the traverse. To close the traverse join AA' and through each angle of the plot draw lines, parallel to AA[1]. Now draw a line aa' equal or proportional to the length of the circuit and divide it up into lengths equal to or proportional to the sides as shown above. Through a draw $a\ p$ perpendicular to aa' and make ap equal to or proportional to the closing error AA'. Join $a'p$ and from the points b,c, d,e, erect perpendiculars to meet the line $a'p$. Now from B along the line drawn parallel to AA' set off BB' equal to bb_1. From the other points carrying out the same construction making CC'$=$ cc_1 etc., join AB', B'C', C'D', D'E' and E'A thus closing the figure. This is only permissible when the closing error is 1 in 300 otherwise the detail when plotted will be distorted.

Note.—If instead of making $aa' =$ to the perimeter we made it $\frac{1}{4}$ or $\frac{1}{8}$ the perimeter then ap would be made $\frac{1}{4}$ or $\frac{1}{8}$ of AA'. Hence bb_1, cc_1, etc. would be $\frac{1}{4}$ or $\frac{1}{8}$ of the real correction required.

38. Another method of plotting a survey of this kind is with the large *circular card protractors* generally used, the better plan is to plot a number of bearings from the same point, and rule the actual lines required parallel to the lines so dotted off. Thus, in example, all the bearings might be laid down from the first position of the protractor at A by dots at say b, c, d, &c., and BC, CD, DE, etc., ruled parallel to Ac, Ad, Ae, etc. This plan avoids the possible error in replacing the protractor each time. The protractor, it will be noticed, when placed correctly on the plan, is really the same as the graduated circle of the compass, and the lines marked off are the various positions of the sights of the compass.

The *circular card protractor* can also be used as follows to plot the bearings of a traverse. The plain centre portion should be cut out to within half an inch all round of the degree divisions, then place the protractor on a meridian as before described with the point from which the bearing is to be drawn lying inside the cut out portion. Now place a brass parallel ruler on the protractor, with one edge on the fore and the other end on the back bearing of the line, and run it up to the point from which it is desired to plot the bearing,—the method will be found very expeditious and accurate when plotting a traverse of short lines with varying bearings.

Should it be required, for the sake of uniformity, to plot the survey with the true north running up and down the paper instead of the

magnetic meridian, a line representing the true meridian is first marked on the paper, the protractor is then laid over this line so that the graduation representing the variation is along this line. The zero of graduation having been thus moved round through the amount of the "variation," all bearings plotted with regard to it will have been laid off with their correct azimuths from the geographical meridian.

39. **Filling in a Survey.**—The prismatic compass is very useful for what is called filling in a survey. The plotting of this kind of work is usually done in the field, each angle being laid down as soon as taken, and each distance and off-set as soon as measured, so that no field-book is required. A piece of paper with the work already done, such as the above circuit of road plotted on it, is placed in a sketching case, and faint parallel lines are ruled over it in a direction at right angles to the meridian, at unequal distances apart, varying from a quarter to half an inch; then, when a bearing is taken, the protractor is placed at right angles to these lines, and the angle at once marked off.

40. **Finding one's place in a Survey.**—The following method of finding one's place in a survey with the prismatic compass will be found useful. Referring to *Fig.* 20, suppose it is desirable to start the filling in from a point G near the tank, and not from any of the former stations, the first thing is to find the position of the point G on the plan; to do this, it is only necessary to stand on the spot, and from there take the bearings of any two convenient stations, in this case D and E; and to protract the angles thus obtained from D and E—their intersection will be the point required. For instance, the bearings of D and E from G are found to be 100° and 205° respectively. Placing a protractor at D and E, plot these bearings, and their intersection gives the point G; of course they must be ruled backwards from D and E, or 180° may be added or subtracted as need be. It will be as well to take a bearing to a third station as a check. Observe that the nearer the two bearings intersect at a right angle, the more accurately will the station be determined.

CHAPTER IV.

INSTRUMENTS, THEIR USE AND ADJUSTMENTS.

41. **The spirit level or level bubble** consists of a glass tube bent or ground into an arc of a circle and it should be so mounted that the plane of the circle is approximately vertical. The Y level is fitted with two screws to control this adjustment. The radius of the arc of this circle is large or small according to the degree of sensitiveness of the bubble. The grinding of the tube must be even, so that the travel of the bubble will be uniform. The tube is very nearly filled with ether and it is then sealed and the air which remains becomes a bubble and always moves towards the highest point of the arc. The size of the bubble varies with the temperature, the bubble contracting under heat and in the middle of the day it is sometimes half the length it was in the morning. Some tubes are fitted with air chambers so that the size of the bubble can be regulated.

The more sensitive a bubble is the more accurate the work, but this holds good only within certain limits since the pitch of screws, quality of lenses in the telescope, graduation of verniers, all rule the limit of sensitiveness of the bubble. A sluggish bubble for reasons given above may also be useless.

The bubble tube is generally graduated and marked in $\frac{1}{10}$ths of an inch from the centre outwards and the sensitiveness of the bubble is known by its angular value for one division of arc of the bubble (see para. 153). Levels should have bubbles with a sensitiveness of 20 to 12 secs. according to size, and Theodolites with a graduation and verniers reading to 20 secs., of about 10 secs. for upper plate and of 20 to 25 secs. for lower plate levels.

The axis of the bubble tube is the line tangent to the bubble arc at its middle point and when the bubble is in the "centre of its run" as it is termed this tangent line is a horizontal line or the axis of the bubble tube is horizontal.

42. (*a*) The **telescope** may be considered to consist of 3 essentials apart from the casing or tube, (1) the object lens with its focussing tube and screw, (2) the eye piece consisting of single or double lenses and (3) the diaphragm or reticule.

(*b*) The **object lens** is a double lens since a single lens would not bring rays to a focus and the image would be fringed with colours, that is a single lens makes rays planatic and chromatic and so that rays will be aplanatic and achromatic two lenses are

used and they are of the double convex and plano concave type, the outer one being double convex of crown glass and the inner one being plano concave of flint glass. The refractive indices of these two kinds of glass supplement each other and the rays are brought to a focus and are colourless.

(*c*) The **eye piece**, when a simple one, has two lenses and the image as seen will be magnified and an inverted one. The erecting eye piece or one used to reinvert the image consists of four lenses and if these are named in order from the eye they are as follows:—eye, field, amplifying and image. The erecting eye piece although it enables the observer to see the image right way up, so to speak, causes a loss of light which does not counterbalance the doubtful advantage in reinverting the image.

(*d*) The **diaphragm or reticule** consists of cross wires, as they are usually called, made of silk or cobweb stretched across a ring but in latter day instruments the wires are engraved on glass. This ring can be moved horizontally or vertically by means of the diaphragm capstan headed screws.

(*e*) The function of the object glass is to focus the object on to the diaphragm and that of the eye piece is to magnify the image as projected on the diaphragm. The focus of one affects the focus of the other and if the plane of the image does not coincide with the plane of the cross-wires **parallax** is said to exist. Some modern theodolites and levels are fitted with an extra lens between the object glass and eyepiece which is used for focussing when the object lens is a fixture.

(*f*) If the component part of lenses of the object glass or eye piece do not coincide at their axes and if the grinding and polishing is not of the best workmanship there is then a **loss in definition.** The amount of light passing through the lenses to the eye compared with the amount of light passing from the object to the eye is what is called **lumination** of a telescope. The larger the object glass the greater the pencil of rays passing through but the edges of lenses cannot be ground to perfection easily and as there is really only an effective diameter in the lenses of the cheaper class of instruments stops are used in the telescope tube to cut off rays from the edges. Under the best arrangements there is a loss of at least 15% of light.

(*g*) The **Magnifying** power of the telescope can be tested by looking at a level rod direct with one eye and through the telescope with the other. The relation between the size of the image and the real will give the magnification. Illumination and magnification are, so to speak, interdependent and the manufacturer has to carefully consider both. The magnifying power of transits are about 20 diameters and those telescopes made specially for stadia work between 20 and 35 diameters.

(*h*) The **size of field** or field of view is the whole circular area which can be seen through the telescope and from edge to edge is usually a degree in arc.

43. **The Magnetic compass** may be of circular pattern fixed in the body of the instrument or may be of the attached rectangular trough pattern. The needle is magnetised and weighted to overcome the dip and rests on a pivot which works on an agate. The compass should not be used when the instrument is not level and the needle should always be thrown off its pivot when not required. In some continental instruments the variation of the needle is neutralised by a slow motion screw which manipulates the graduated arc and the needle is thus made to point to zero instead of a deflection of so much E or W of North.

44. **The Theodolite** is the most important instrument used by surveyors, and measures at the same time angles and *altitudes, i.e.*, the horizontal angle between two objects is observed, and the angles of elevation or depression of these points above or below the horizontal plane of the axis of the telescope.

Description of the Theodolite.—The instrument is a somewhat complicated one, and beginners are often confused by the number of parts, but if the reader will consider it with reference to its uses, he will find it quite simple. It really only consists of two main parts, the *Lower Plate* and the *Upper Plate*. The Lower Plate is a circular metal plate, *see* L in *Fig.* 30 graduated to 360° round its edge; it corresponds to the graduated circle in the prismatic compass, or the protractor in plotting. It is the base of the instrument, and is mounted on a stout steady tripod, and provided with levelling or footscrews P, P, to adjust it in a horizontal plane. It is free to turn round a central vertical axis, but has clamping (C) and micrometer (T) screws to fix it in any desired position. For explanation of these, *see* para. 44 *(a)*. A small compass, G, is attached to the instrument, by which the zero line of the graduated circle can be brought into the north line and fixed there by its clamping screw. This operation may be the base of some work with the theodolite, as then, as will be seen,

all angles read are really bearings, and in plotting, the protractor, which is nothing but the lower plate on the plan, is always in the same position with its Zero line up and down the plan. The bearings being those from magnetic north.

The second main part of the theodolite is the Upper Plate ; this nearly covers the lower, lying flat on it, and turning on the same axis as it, but freely and independently. It has its own clamping and tangent screws *c* and *t*, by which it can be fixed to the lower plate so as to turn with it as one piece when required to do so. It carries the two levels B, B, by which the two plates together are adjusted to a horizontal plane by the use of the footscrews P, P.

Fixed on to the upper plate, so as to always turn with it, is the telescope. This has a fine wire, or really cobweb* fixed in it, similar to the vane sight of the prismatic compass, and answers to the sight line of that instrument, but as the telescope magnifies, long sights to distant objects can be taken with great accuracy.

The working is exactly as with the prismatic compass, only the graduated circle or lower plate will not swing of itself, but must be fixed north and south. The upper plate or sight can then be turned in any direction to take the angle with the zero line. A vernier scale is provided on the edge of the upper plate, as at V in figure 31 to show the angle. It will, however, be evident, that we *need* not start with the north line, but can fix the vernier at the zero, clamping the two plates together, and turn the two as one, till the sight intersects any one object, and then clamp the lower plate. The upper plate can then be released from the lower, and the actual angle between the first and any other objects read off.

In order to allow the telescopic sight to be fixed accurately on a high or a low object, when taking horizontal angles, and also to take vertical angles, it is mounted on a horizontal axis A, and so can be turned up or down as required, and this motion being in a vertical plane does not interfere with the measurement of the horizontal angle (see para. 93). There are of course also clamping and tangent screws for this motion, marked C and *i*. (fig. 30).

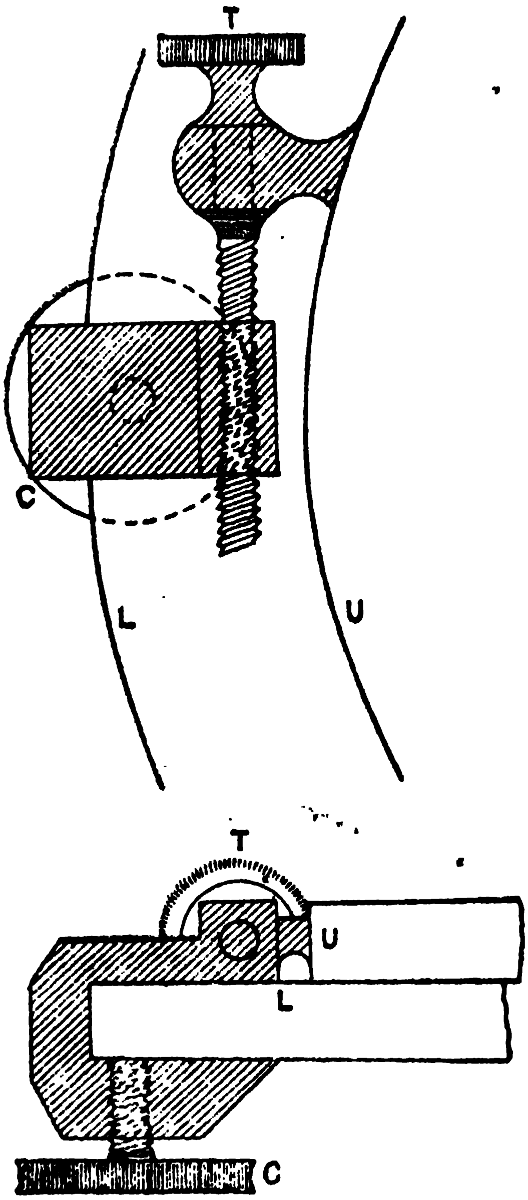
When the sight line of the telescope is really level, as shown by the bubble *b*, the graduated scale on the vertical arc reads zero on the fixed vernier at its lowest point, and thus any angle in the vertical plane can be measured.

(a) **Clamping and Tangent Screws** are used in all instruments, where one part slides and has to be adjusted accurately on another. Thus

* Modern theodolites are fitted with engraved diaphragms.

in *Fig.* 23 let U and L be part of the edge of upper and lower plates. Then the vertical clamping screw C fixes the two together, the connection being shown by the shaded part which *contains* the horizontal tangent screw T. If this be now turned, U is caused to move on L by a very gentle motion, as the screw is a fine one, and of course the motion is only possible for a short distance. Thus the procedure is with L fixed and screw C loose to set the limb U nearly on the object by hand, then clamp C, and then finally adjust on object by T. It is very necessary before commencing an observation, to see that the tangent screw is at about the middle of its run. Neglect of this may cause the whole operation of sighting the observed object to be made over again, and lead to great loss of time.

Fig. 23.



Detailed descriptions of the forms of theodolites in most common use, and the permanent adjustments necessary to put them in thorough working order, are given in the following pages, but with the foregoing explanation any one should be able to understand the actual working with the instrument which is given at para. 52 *et seq.* The Permanent Adjustments are only necessary when the instrument is first put together at the makers, or if it has been very badly used; for ordinary work the instrument does not need to be in strict adjustment as the methods of observation eliminate errors due to such.

Theodolites are of various modes of construction, and it will be necessary here to describe the three patterns in use in India. Before describing them, however, it will be as well to get an insight into the principles of the vernier, the means by which both the horizontal and vertical angles are read. The method of using fixed vernier scales was described in para. 13; the principles of both the fixed and movable are just the same, but the methods of reading quite different.

(*b*) **The Vernier.**—The vernier is a contrivance for measuring off parts of the space between the equidistant divisions on the limb of a divided circle, arc, or any graduated scale; it attains this object by measuring the differences between the divisions of two approximating scales one of which is fixed and called the primary scale the other movable and called the vernier.

If a number of parts, say, $n-1$, be taken from the primary scale, and a space equal to this be transferred to the movable scale, and divided into n parts *i.e.* into parts whose number is greater by 1 than that in the length taken from the primary scale, these parts will each be smaller than the first by the nth part of a division on the primary scale.

For let a = length of a division on the primary scale.
b = length of a division on the movable scale.

Then by hypothesis—

$$(n-1)\,a = nb$$
$$\text{or } na - a = nb$$
$$\text{and } a - \frac{a}{n} = b$$

That is, b, a division on the movable, is smaller than a, a division on the fixed scale, by the nth part of a.

The proper number of divisions for a vernier scale is very easily found. Suppose the primary scale is divided to 10 minutes, and the vernier is required to read to 10 seconds; then using the same notation.

$$a - b = 10'' = \frac{a}{60}$$
$$\text{or } 60a - 60b = a$$
$$\text{or } 59a = 60b$$

that is, in order to read to 10″, a length of 59 divisions of the primary scale must be taken and divided into 60 parts for the vernier scale.

Again—construct a vernier to read to 15″, the primary scale being divided to read 20′.

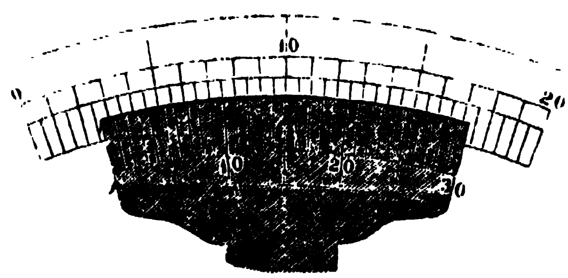
$$\text{Here } a - b = 15'' = \frac{a}{80};\ \left(\frac{15''}{20'} = \frac{15}{1200} = \frac{1}{80}\right)$$
$$or\ 79a = 80b$$

so that 79 divisions of the primary scale would be divided into 80 parts of the vernier.

(*c*) Many students appear to find great difficulty in reading the vernier, consequently several examples are here subjoined, though it is only by actual practice that any degree of celerity can be obtained.

Ex. 1.—The graduated arc of the pocket sextant shows directly degrees and half degrees, and the vernier reads to minutes.

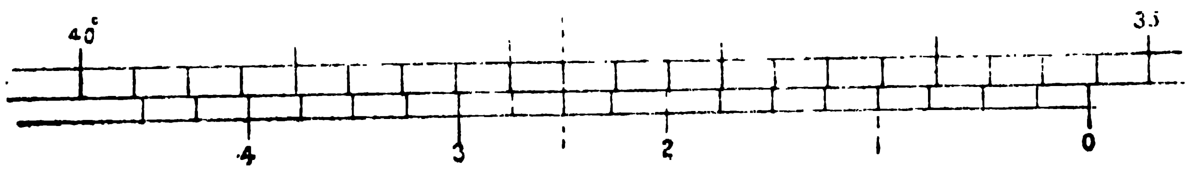
Fig. 24.



In the figure, 20° of arc are shown, and the vernier is shaded to distinguish it better. Here 30 divisions on the vernier exactly correspond in length to 29 on the arc. To read the angle; first note where the zero (shown by an arrow) of the vernier rests; here it lies somewhere between 2° 30′ and 3°. Next, examine the vernier, and run the eye along the lines until a division of the vernier is found to coincide with a division of the primary arc. In this case the 15th division appears to coincide with one on the arc: this shows that 15 more minutes have to be added to the first reading; the true angle, therefore, is 2° 30′ + 15′ = 2° 45′.

Ex. 2.—In this example the primary arc shows directly to 15′ and the vernier reads to 15″. The main divisions on the vernier show minutes and the sub-divisions quarters of

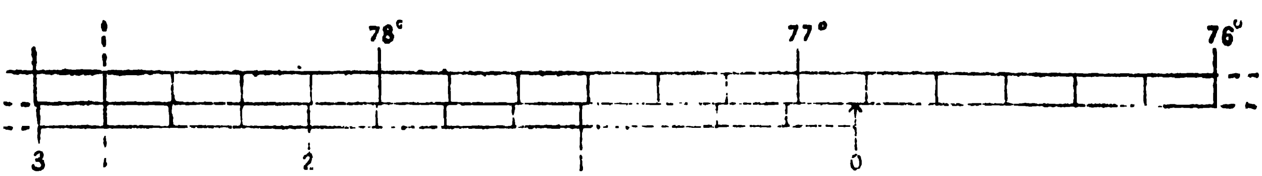
Fig. 25.



minutes. To read this angle: the zero of the vernier has passed by 35° 15′, and the coincident lines are at the 2nd sub-division after the 2nd principal division of the vernier. The angle on the vernier, therefore, is 2′ 30″, and this being added to the former reading gives the true reading as 35° 17′ 30″.

Ex. 3.—The limb is here divided into 10′, and the vernier, as in last example, reads to

Fig. 26.

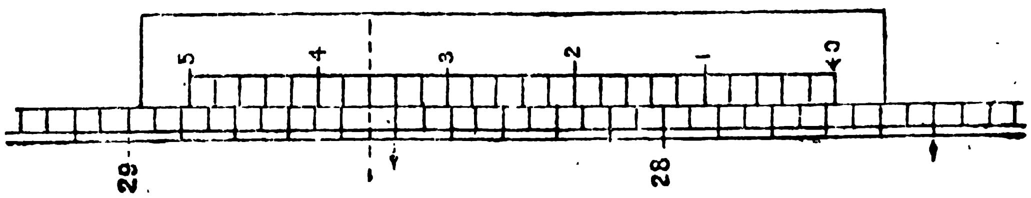


15″. The zero of the vernier has passed 76° 50′, and the vernier shows 2′ 45″; consequently the reading is 76° 52′ 45″

To make this vernier it will easily be seen that a length of 39 divisions has been taken and divided into 40 parts for the vernier, for 15″ is the $\frac{1}{40}$th of 10′.

Ex. 4.—This figure represents (to double size) the usual scale of the English Mountain Barometer. The scale is first divided into inches; these are sub-divided into tenths by the

Fig. 27.



longer lines, and the shorter lines, again divide these into halftenths or five-hundreths: 24 of these smaller parts are set off and divided into 25 parts on the vernier, each of which therefore $= \frac{24 \times \cdot 05}{52} =$ ·048 inch, and is shorter than a division on the scale by ·050—·048 = ·002, or the $\frac{1}{500}$th of an inch, to which minuteness the vernier can therefore be read.

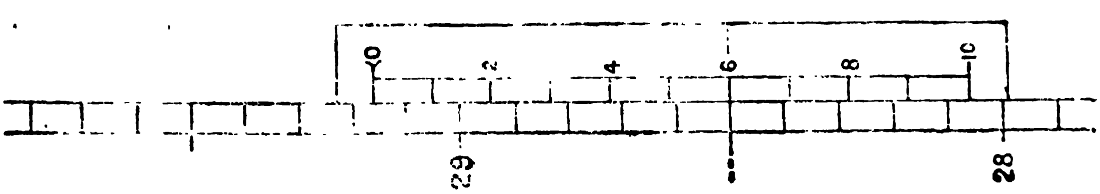
$$\text{Here } 24a = 25b \text{ where } a = \tfrac{1}{20} \text{ inch.}$$
$$\text{or } 25\,(a-b) = a$$
$$\text{or } a-b = \frac{a}{25} = \frac{\frac{1}{20}}{25} = \frac{1}{500}$$

The reading in the figure is 27·686 (27·65 by the scale and ·036 by the vernier), the dotted line showing where the concidence is.

In explaining the principle of the vernier (n—1) parts of the primary scale were taken and divided into n parts for the vernier. The explanation applies equally if $(n+1)$ parts instead of $(n-1)$ had been taken. In this case each division on the vernier is $\frac{1}{n}$ longer than a primary division. In using verniers graduated in this manner, there is the inconvenience of being obliged to number the lines of the vernier and to count their coincidences with the lines of the scale in a retrograde or contrary direction to that in which the numbers of the scale run.

Ex. 5.—The figure represents (to double size) rather more than an inch of the scale attached to the common barometer. The inches are divided into tenths, and on the vernier

Fig. 28.

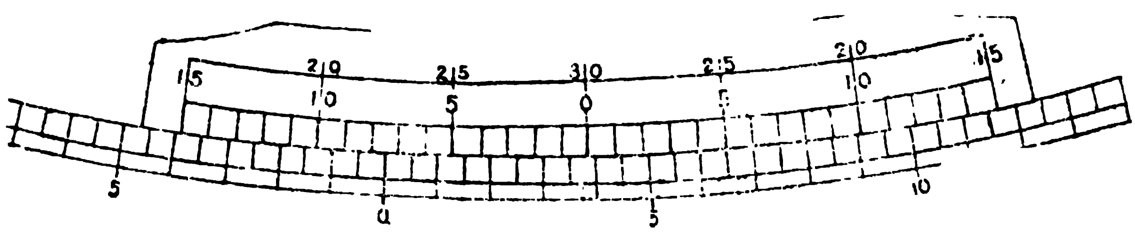


11 of these are divided into 10 parts; therefore, by analogous reasoning, each space of the vernier overlaps a space on the scale by the one-hundredth of an inch. The manner of reading this vernier is the same as in the last example, except that the numbers run in a reverse direction. The zero of the vernier is brought to the level of the top of the mercury, and the reading then taken; in this case it shows a height of 29·16 inches.

Ex. 6.—This figure represents another form of vernier, and one which is sometimes applied to the vertical arc of the Everest theodolite. The limb is divided into half degrees, and the vernier reads to minutes, 30 parts on it being equal to 31 on the limb. But as the

zero is placed in the centre, the vernier appears only half its proper length, reading only to 15 minutes on either side. Above the first row of figures there is another row, and the upper figures on one-half are a sort of continuation of the lower cnes on the other half. Thus, in moving the index to the right, read the *lower* figures on the left hand vernier at any coincidence, when the space passed over is less than 15′: but if it be more, read the *upper* figures on the right hand vernier, and *vice versa.* In the present case the reading is 8° 54′ (8° 30′ on limb and 24′ on vernier).

Fig. 29.



The vertical verniers of some double arc Everest Theodolites have the zero at one end of the scale and in both cases it will be found that the following memory rule will simplify the reading difficulty. Consider the 0° degrees of the primary scale as the starting point and when this zero is *above* the arrow of the vernier scale read vernier scale from *top* downwards and when the zero of the primary scale is *below* the arrow of the vernier read from *bottom* upwards or in other words read the vernier always in a direction from 0 of the primary scale to 0 of the vernier.

45. **Description of the ordinary Y Theodolite.**—The horizontal limb is composed of two circular plates L and V, which fit accurately one upon the other. The lower plate projects beyond the other, and its projecting edge is sloped off, and graduated at every half degree. The upper plate is called the vernier plate, and has portions of its edge sloped off, so as to form with the sloped edge of the lower plate continued portions of the same conical surface. These sloped portions of the upper plate are graduated to form the verniers, by which the limb is sub-divided to minutes. The five-inch theodolite *represented in *Fig.* 30 has two such verniers 180° apart. The lower plate of the horizontal limb is attached to a conical axis passing through the upper parallel plate, and terminating in a ball fitting in a socket, upon the lower parallel plate. This axis is hollowed to receive a similar conical axis, ground accurately to fit it, so that the axis of the two cones may be exactly coincident. To the internal axis, the upper, or vernier plate of the horizontal limb is attached, and thus, while the whole

* It is usual to characterise a Theodolite according to the diameter of its horizontal circle; so that when this latter measures five inches, the instrument is called a 'five inch theodolite'.

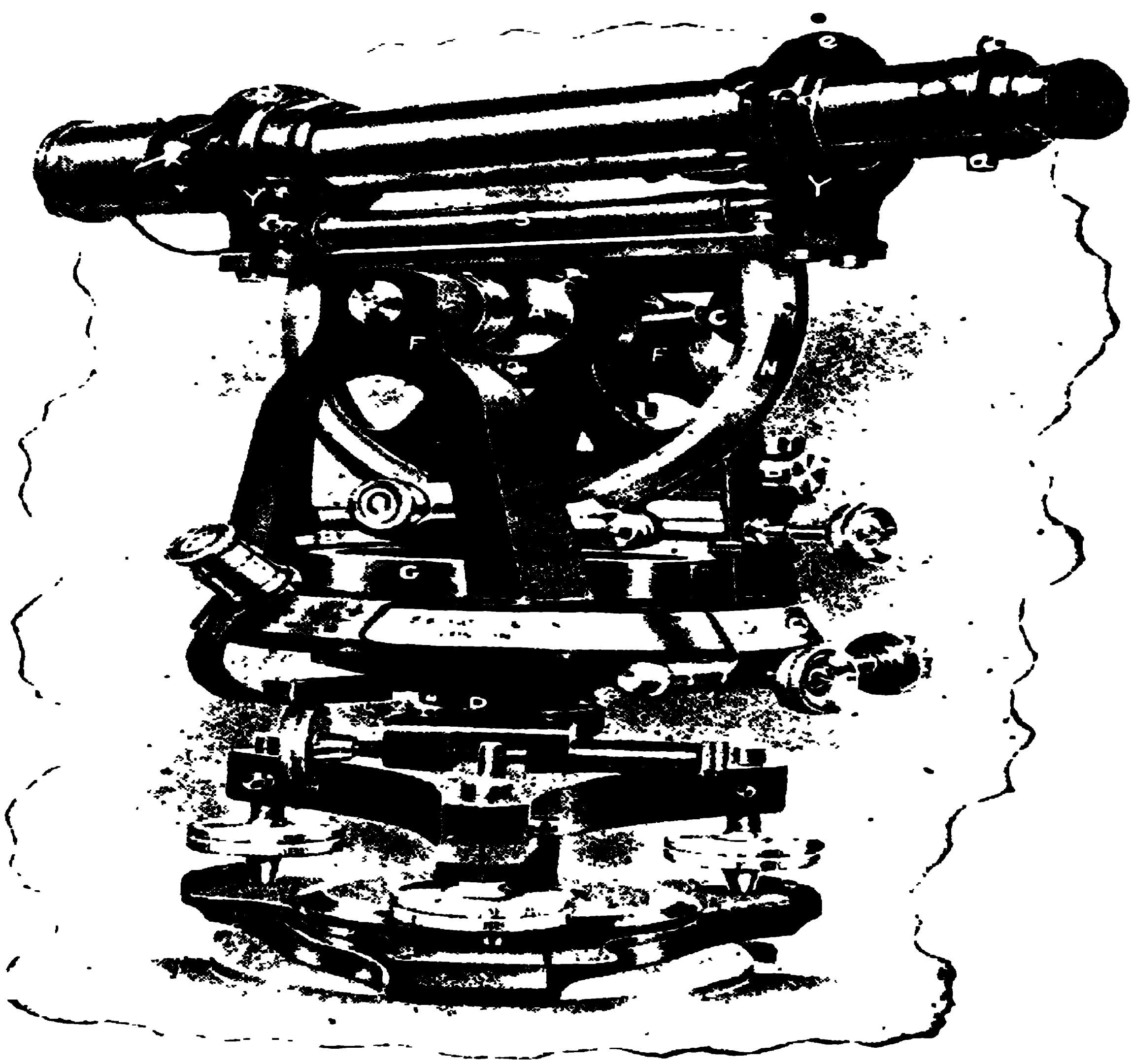


Fig. 30.

limb can be moved through any horizontal angle required, the upper plate only can also be moved through any desired angle, when the lower plate is fixed by means of the clamping screw C (hidden in figure by the instrument axis) which tightens the collar D. T is a slow motion screw, which moves the whole limb through a small space, to adjust it more perfectly, after tightening the collar D by the clamping screw C. There is also a clamping screw *c* for fixing the upper plate to the lower, and a tangent screw *t*, for giving the upper plate a slow motion upon the lower, when so clamped. Two spirit levels B B are placed upon the horizontal limb, at right angles to each other, and a compass G is also placed upon it, in the centre between the supports FF of the vertical limb.

The vertical limb NN is graduated on one side at every 30 minutes, each way from 0 to 90°, and sub-divided by the vernier, which is fixed to the compass box plate, to single minutes. Upon the other side are engraved the number of links to be deduced from each chain, for various angles of inclination, in order to reduce distances measured on ground rising or falling at these angles, to the corresponding horizontal distances. The axis A of this limb must rest in a position truly parallel to the horizontal limb, upon the supports FF, so as to be horizontal when the horizontal limb is set truly level, and the plane of the limb NN must now be perpendicular to its axis. On the top of the vertical limb NN is attached a bar that carries two Y's (so called from their shape), for supporting the telescope, which is secured by two clips *c* and *d*; and underneath the telescope is a spirit level *ss*, attached to it at one end by a joint, and at the other by a capstan-headed screw. The vertical axis A can be fixed by a clamping screw C and the vertical limb can then be moved through a small space by the slow motion screw *i*.

46. **Line of Collimation, &c.**—Before describing the methods of 'adjustment,' it is necessary that the student should understand the conventional terms used, e g. the optical axis of the instrument, the line of collimation, the virtual line of sight.

The first two of the following definitions are extracted from Loomi's Practical Astronomy:—

(1) The optical axis of a lens is the line which joins the centre of the spherical surface by which the lens is bounded. When a telescope is properly constructed, the axis of the object-glass and eye-glass must be in the straight line which joins the 'centre' of the object-glass and eye-glass. The straight line is called the **optical axis** of the telescope.

(2) The principal line of sight, or **line of collimation** is determined by the direction of the ray of light which passes through the 'centre' of the object-glass and the point of intersection of the cross hairs.

(3) The term '**Virtual Line of Sight**' has been proposed for the 'locus of points observed,' by Lieutenant-Colonel A. Cunningham, R.E., who thus defines it—

After *first* duly focussing the wires and field of view; *second*, removing any relative parallax of the wires and field; all points in the field of view at whatever distance, which are bisected, or covered, by the intersection of the cross hairs, will be on a certain straight line, which may be conveniently called the *Virtual Line of Sight* (being the locus of points observed).

47. **Permanent Adjustments.**—The following are the *permanent* adjustments. [The *Temporary* adjustments required every time the instrument is set up are described in paras. 59 and 60.]

1. *Adjustments of the telescope for collimation.*

2. *Adjustments of the vertical limb for setting the level beneath the telescope to indicate the horizontality of the line of collimation.*

3. *Adjustments of the horizontal limb for setting the levels on the horizontal limb to indicate the verticality of its axis.*

1. *Collimation.*—First direct the telescope to some well-defined object at a distance of not less than 100 yards, and proceed as described under heading "*Focus* and *Parallax*" in para. 60; see that the intersection of the cross wires cuts it accurately; then loose the clips *e*, *d*, that confine the telescope in the Y's, and turn it round on its axis, observing whether the centre of the wires still continues to cut the object, during a whole revolution. If it does, it is in adjustment; if not, the line of collimation does not coincide with the axis of the "telescope-bands" (on which the telescope turns). *To correct this error*, turn the telescope on its axis until one pair of the conjugate or diaphragm screws *a*, *a*, is in the same vertical line, and direct the intersection of the cross hairs on some well-defined object. Now turn the telescope half round in the Y's and correct the vertical movement of the intersection of the cross hairs, half by the vertical tangent screw, and half by the vertical diaphragm screws. Now make the other pair of diaphragm screws assume the vertical position and repeat the process. This must be repeated till the cross wires cut the same point of the distant object during an entire revolution of the telescope round its axis.

2. *Adjustment of the vertical limb.*—The bubble of the level *ss* being in the centre of its tube, reverse the telescope end for end in the Y's and, if the bubble does not remain in the same position, correct for one-half of the error by means of the capstan-headed screw at the end of level and for the other half by the vertical tangent screw *i*. Repeat the operation till the result is perfectly satisfactory. Next turn the telescope round a little, both to the right and to the left, and, if the bubble does not remain in the centre of its run, the level *ss* must be adjusted laterally by the screw at the other end.

3. *Adjustment of the horizontal limb.*- Set the instrument up as level as you can by the eye, by moving the legs of the stand. Tighten the collar D by the clamping screw C, and unclamping the vernier plate, turn it round till the telescope is directly over two of the parallel plate screws. Bring the bubble *b* of the level *ss*, beneath the telescope, to the centre of its run, by turning the tangent screw *i*. Turn the vernier plate half round, bringing the telescope again over the same pair of parallel plate screws; and, if the bubble of the level be not still in the centre of its run, bring it back to the centre, half-way by turning the parallel plate screws over which it is placed, and half-way by turning the tangent screw *i*. Repeat this operation till the bubble remains accurately in the centre of its run in both positions of the telescope; and, then turning the vernier plate round till the telescope is over the other pair of parallel plate screws, bring the bubble again to the centre of its run by these screws.* The bubble will now retain its position while the vernier plate is turned completely round, showing that the internal axis, about which it turns, is completely vertical. The bubbles of the levels on the vernier plate should now also be in the centres of their runs; if not, they must be brought so wholly by means of the adjusting screws at either end of the level tube. Now, having clamped the vernier plate, loosen the collar D by turning back the screw C, and move the instrument slowly round on the external axis, and if the bubble of the level *ss* maintains its position during a complete revolution, the external and internal axis are coincident, both being vertical at the same time; but, if the bubble does not maintain its position, it shows that the two parts of the axis have been inaccurately fitted, and the fault can only be remedied by the instrument-maker.

There only remains now to determine the *zero of altitude*; the axis is now vertical and the telescope horizontal, consequently the vernier of the vertical arc should read zero; if it does not, the vernier plate may be

* Four footscrew instrument.

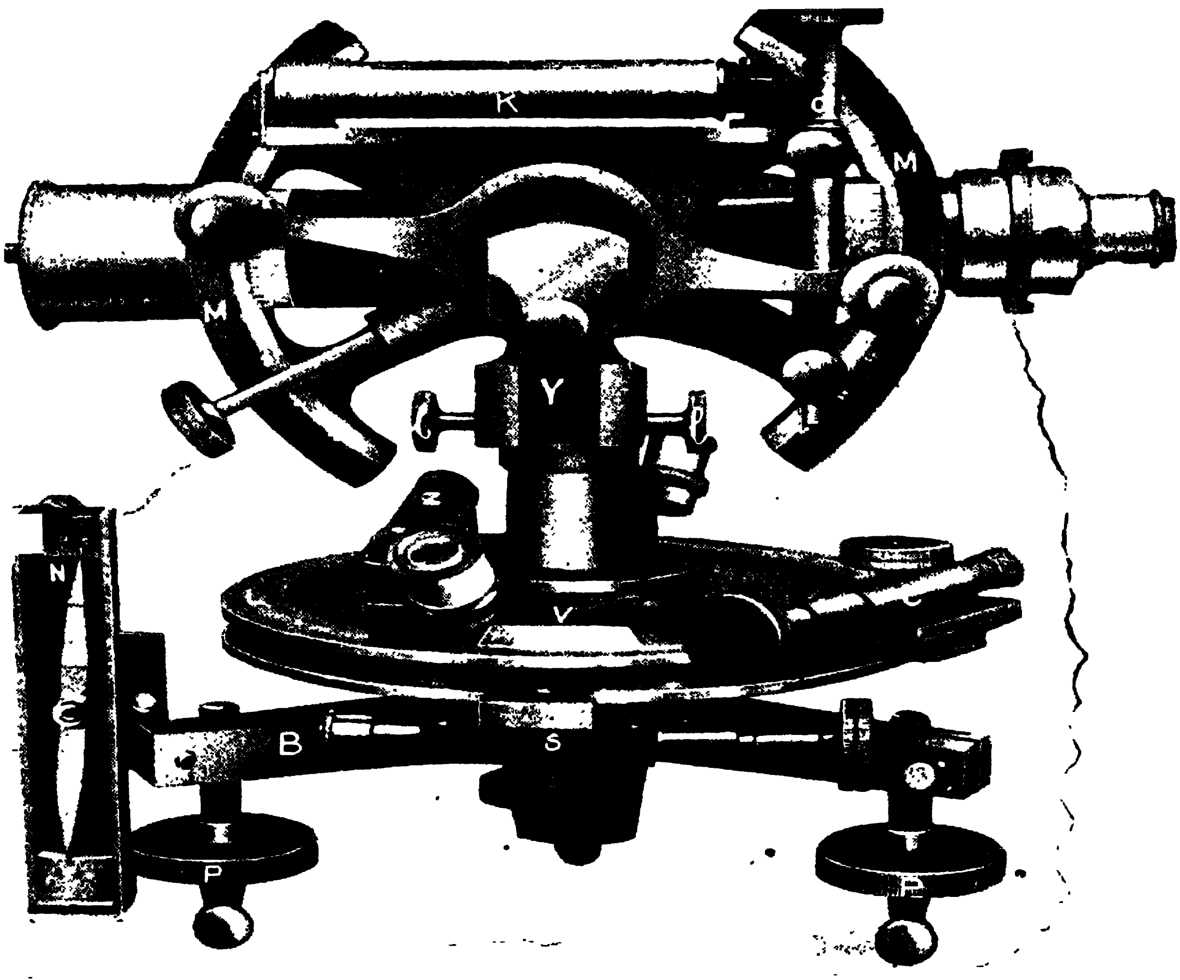
unscrewed and placed so as to do so, but the better way is to note as an index error whatever the vernier may read, and apply it with its proper sign, to all vertical angles.

48. **Description of Everest's Double Arc Theodolite.**—Another type of theodolite used in India was designed by Sir George Everest and is generally known as "Everest's Pattern." There are two patterns really, the "Single Arc Everest" and the "Double Arc Everest," but with the exception of one having two vertical arcs while the other has only one, they differ so little that a description of one nearly suffices for the other.

The horizontal circle, or limb L, Fig. 31, of this instrument consists of one plate only which, as usual, is graduated at its circumference. The index is formed with two or more radiating bars, having verniers (two verniers VV′ in fig.) at the extremities of them, for reading the horizontal angles, another carries a clamp C to fasten the index to the edge of the horizontal limb, with the accompanying tangent-screw for slow motion. These are connected with the upper part which carries the telescope, and turning upon the same centre, show any angle through which the telescope may have been moved. The instrument has also the power of repeating the measurement of an angle; for the horizontal limb being firmly fixed to a centre, movable with the tripod support, B, and governed by a clamp and tangent screw, S, can be moved with the same delicacy, and secured with as much firmness as the index above it.

The tripod support, which forms the stand of the instrument, has a footscrew P at each extremity of the arms which form the tripod; the heads of the footscrews are turned downward, and have a flange (or shoulder) upon them, so that when they rest upon the triangular plate fixed upon the staff-head, another plate locks over the flange, and being acted upon by a spring, retains the whole instrument firmly upon the top of the stand.

The telescope is mounted in the following manner:—The horizontal axis (only the near end of which is seen) and the telescope form one piece, the axis crossing the telescope about its middle, and terminating at each extremity in a cylindrical pivot. The pivots rest upon low supports (only one of them, Y, being visible in the figure), carried out from the centre, on each side, by a flat horizontal bar, to which a spirit-level, Z, is attached for adjusting the axis, to the horizontal plane. The vertical angles are read off on two arcs of circles, MM, which have the horizontal axis at their centre, and being attached to the telescope move with it in a vertical plane. An index, upon the same centre, carries two verniers *v*,*v*,



ig. 31.

and has a spirit-level, K, attached to it, by which it can be set in a horizontal position, so that whatever position the telescope, and consequently the graduated arcs may have, when an observation is made, the mean of the two readings will denote the elevation or depression of the object observed above or below the horizontal plane. On the upper part of the telescope is fixed a narrow box, N, containing a magnetic needle, for observing the bearings of objects.

49. **Permanent Adjustments.**—The following are the permanent Adjustments of this instrument:—

1st. *Of the lower level.*—To set the level parallel to the horizontal plate.

2nd. *Of the line of collimation* (in azimuth). To set the line of collimation at right angles to the horizontal axis.

3rd. *Of the upper level and virtual line of sight.**—To set the upper level at the same inclination to the zero line of the verniers, as is included between the "virtual line of sight" and telescope- axis.

But it may be remarked that, neither the second nor third adjustment is absolutely necessary The simple expedient of observing every point twice (or an even number of times) with the vertical arcs in an opposite position or with face charged (see para. 57) on each occasion eliminates all errors due to non-adjustment of the line of collimation, and mean line of the verniers.

1st. *Adjustment of the lower level.*—Turn the telescope so that the lower level may be directly over one foot-screw, † bring the bubble to the centre of its run by that footscrew; next turn the telescope till the bubble is over the other two footscrews and with these footscrews (see para. 59) bring the bubble again to the centre; return to the first position and correct by the first footscrew used and repeat these two operations till perfect. Now turn the bubble end for end over the first footscrew and correct half the error by this footscrew and half by the bubble nuts when the axis of the bubble will be made horizontal. Having perfected this, the levelling of the instrument is completed by turning the telescope a quarter round, so that the level may be over the other two footscrews

* This adjustment has been retained in this edition since there are many engineers, in India who still adjust a theodolite as if it were a level, but it is suggested that paras. 53 to 58 which apply equally to this class of instrument contain the more up to date methods.

† One footscrew first always as two footscrews mean that the hands must make an equal motion with each footscrew in order that this adjustment can be correctly done. This does not apply to temporary adjustments.

by which the bubble is to be brought to the centre of its run. Repeat till perfect when the bubble should remain in the centre of its run no matter in what direction the telescope points.

2nd. *The line of Collimation in Azimuth.*—Having levelled the instrument as above, and having intersected some distant and well-defined object with the cross wires of the telescope (as described in para. 60) clamp the lower plate. Invert the telescope and turn the upper plate through 180° that is change face (see para. 51) and if the object be still intersected, the collimation is perfect (in azimuth). If not, correct half the error in azimuth by the screws that give horizontal motion to the diaphragm carrying the cross hairs, and the other half by the tangent screw, giving motion in azimuth to the instrument. Repeat till perfect. *Only two of the four screws, by which the diaphragm is generally secured in the telescope are necessary therefore for this adjustment.*

To conform more closely to the adjustment given for transit theodolites an alternative method is given as follows. Having intersected some well defined object on one face by clamping the lower plate and using the slow motion screw register the reading. Next change face (see para. 51) reintersect object by clamping upper plate and using slow motion screw for the upper plate and again read. If the readings differ by 180° the instrument is in adjustment; if not set the vernier to the mean reading and it will be found that on looking through the telescope the wire is no longer on the object: adjust the error by the two horizontal diaphragm screws. The lower plate will remain clamped throughout this operation.

3rd. *Adjustment of the upper level and virtual line of sight.*—The object of this adjustment is to set the telescope level-axis at the same inclination to the mean line of the vertical reading verniers that is included between the "virtual line of sight" and telescope-axis.

The process consists in making the "virtual line of sight" and telescope level axis simultaneously horizontal, at the same time that the mean vertical reading is zero.

[*Caution.*—It is essential that the two first Adjustments should have been performed before attempting the third.]

Step 1.—***To trace a level line in the air.***—Place two pegs A and B at any convenient distance (say 150 feet) apart on a tolerably level piece of ground. Set the instrument up over the point midway between the pegs A,B, and level its horizontal plates by means of the lower level and footscrews. Tighten the stud-screws or antagonistic screws *ll*, and clamp the vertical arc in any convenient position—say at zero. Direct the telescope on a levelling staff placed on either peg: focus the wires and figures on the staff and at the same time destroy any relative parallax (of the wires and figures on the staff), by means of the eye-piece motion and focussing screw, see para. 60.

Next make the vertical axis of motion (as yet only approximately vertical) truly vertical by means of the footscrews in the same manner as described for the first adjustment.

Direct the telescope (already properly focussed) on the levelling staff placed upright on the peg A, and record the reading; next turn the telescope, turning gently round the vertical axis, and record the reading on the same staff removed to the peg B.

The difference (if any) of these readings will be the true difference of level of the tops of the pegs A, B (notwithstanding instrumental errors).

Next gently tap the *higher* of the two pegs (this corresponds to the *lesser* reading) into the ground. Place the staff on it and again observe the reading. Continue tapping whichever peg is the *higher* into the ground until the reading on the staff is the same on both pegs. This can be easily done after a few trials. The tops of the pegs will now be *on the same level.*

[*Caution.*—To ensure that the staff shall always rest on the same point on the pegs drive a small nail not quite home into the tops of the pegs. The *same* staff should be used *for both pegs*, both in this and the next process, as the differences of graduation of different staves might introduce an error larger than the existing error of line of collimation. The act of moving the eye-piece frequently disturbs the level: for this reason it is directed above to complete the focussing *before* finally setting the vertical axis of motion vertical.

After once tightening the stud-screws, and clamping the vertical arcs as above, the stud-screw, vertical arc-clamp, and tangent-screw, must not be touched throughout the remainder of the process.

The horizontal plates *must be kept level throughout*: the lower level alone can be trusted to for determining this—(the upper level is of no use for this purpose): any deviation of the bubble (of the lower level) from its centre is to be corrected by the footscrews.]

[*Note* that this first STEP of "tracing a level line in the air" *is much more easily* performed with the aid of a Levelling Instrument (*see* Chapter VI) than as here described with the Theodolite itself.]

STEP II.—*To set both the telescope level-axis and "virtual line of sight" horizontal, whilst the vertical arcs read zero.*

Adjustment.—Remove the instrument on to the line AB *produced*, at a sufficient distance from the nearer peg to admit of distinctly reading the staff when placed thereon. Level its horizontal plates by means of the lower level and footscrews.

Clamp the vertical arcs so that their mean reading shall be zero. Direct the telescope towards the pegs with the "stud-screws" tightened so as to bring the upper level bubble at the centre of its run, so that the "virtual line of sight" may be *nearly horizontal*; and record the readings on the same staff placed successively on either peg—after duly foccussing without parallax in each case.

[*Caution.*—The vertical arc-clamp and tangent-screw must not be touched after once setting to zero.]

If these readings differ, the "virtual line of sight" is not really level, in which case it must be tilted by gently tilting the whole upper works by means of the "stud-screws"—watching the effect on the readings on the staff through the telescope

[*N.B.*—The object-glass is to be *depressed* if the reading on the further staff *exceed* that on the nearer, and *vice versa*.]

Repeat the reading on the staff on either peg, and continue tilting the telescope (by means of the stud-screws) until the readings become *precisely the same.*

The "virtual line of sight" will then be a horizontal line. Now since the stud or antagonistic screws have been used it stands to reason that although the virtual line of sight is made horizontal the axis of the bubble to be horizontal must be also parallel to the line of sight. The stud screws have upset the horizontality of the bubble so the bubble must now be brought back to the centre of its run by means of its own capstan head screws.

Result.—The upper level axis and "virtual line of sight" will now be both horizontal whilst the vertical arcs are at their zero, so that in future a zero mean reading on the vertical arcs with the upper level bubble at the centre *will indicate the horizontality of "the virtual line of sight."*

50. **How to change face.**—The face of a theodolite is the vertical arc, and, according as the vertical arc is on the left or right of the observer when he is looking through the telescope, so the instrument is said to have **left** or **right** face. In changing face, the diaphragm is inverted or turned through 180° and the horizontal arc is also turned half round or through 180°.

When the theodolite is a "transit" and its telescope can be completely revolved in the vertical plane, changing face is to so revolve it end for end or through 180° and then to turn the horizontal arc through 180°. It will now have changed face and will be pointing as before.

(Caution in setting up a theodolite—always note that A horizontal arc vernier, is or should be, the vernier directly beneath the vertical arc).

With the double arc Everest the process is a little more complicated, because the telescope cannot be completely revolved in the vertical plane. It has to be taken out of its Y's and the following three half turns have to to be made :—

(1) The vertical arc verniers are made to change places.

(2) The pivots or trunnions, which rest in the Y's are made to change places.

(3) The diaphragm is inverted and when the telescope is put back in the Y's two essential points must be secured, viz. (1) the telescope should point as before, and (2) each trunnion should sit in the proper Y.

Hence the following *modus operandi* :—

(1) Remove the compass and sometimes also the clamping screw of the vertical arc.

(2) Loosen the stud or antagonistic screw and open the Y's.

(3) Unclamp the vertical arc if not already unclamped and lift the telescope out of its Y's taking care to keep it *always* horizontal with its object-glass pointing to the object. This should be done without jar or shake.

(4) Now make the three half-turns, viz.:—

(a) Turn the vertical arc vernier's till they change places, the level going undermost;

(b) Turn the telescope round its optical axis through 180° whereby the diaphragm will be inverted, the level will come uppermost, and the trunnions will change places; also the vertical arc will go over to the other side, technically called *changing face.*

(c) Turn the horizontal arc through 180°, which will make the Y's change places, so that they will receive the trunnions proper to them, and the horizontal *A vernier will continue to be just under the vertical arc*

(5) Replace the telescope in the Y's tightening the antagonistic screws and closing the clips of the Y's.

The Y's and trunnions are not inter-changeable unless the workmanship of the instrument is very perfect: for this reason each trunnion is made to sit in its proper Y and this is always indicated by the presence of the horizontal A vernier just under the vertical arc.

Since changing face is not convenient with the double arc Everest and since there is always the chance of a jar and the possible displacement of the horizontal arc it will be seen that it is not the instrument to use on triangulation or for star observations if a *transit,* which has none of these inconveniences, is available. Owing to its more compact form and there being no necessity to change face, it is a popular instrument in *traversing* for which it was probably really designed.

51. **Description of Everest's Single Arc Theodolite.**—This, as its name implies, has only one vertical arc; on this account vertical readings can only be taken on one face of the instrument, for on inverting the telescope (by turning the axis end for end) and bringing the screws which retain the index underneath, the index and the arc will be found on opposits sides of the axis.

In other respects the instrument differs little from the double-arc; the single-arc usually has only two, instead of three verniers, to read the horizontal plate; the vertical arc has sometimes only a rack and pinion motion (without clamp or tangent screw) and the level attached to the vertical index is fixed by the maker, and does not therefore admit of adjustment.

Permanent Adjustments.—Here follow the *permanent* Adjustments of this instrument: these are the same in *name* and *object* as for the double-arc instrument, *q. v.* The second Adjustment is not absolutely

necessary (for the same reasons as explained under the double-arc,) but the third cannot well be dispensed with *if correct vertical readings are required.*

ADJUSTMENT 1ST.—Similar to that for the double-arc.

" *2nd.*— " " "

" *3rd.*—Very similar to that for the double-arc.

STEP I.—As for the double-arc instrument, with the precaution that if there be no vertical arc-clamp (as commonly happens), the arc should be set to zero *before making each reading* on the staff and again examined after the reading: the reading should be rejected if the arc is not still at zero.

STEP II.—*To set both the telescope level-axis and "virtual line of sight" horizontal whilst the vertical arcs read zero.*

ADJUSTMENT.—Remove the instrument on to the line AB *produced,* at a sufficient distance from the nearer peg to admit of distinctly reading the staff when placed thereon. Level its horizontal plates by means of the lower level and footscrews.

Direct the telescope towards the pegs. Bring the upper level bubble to the centre of its run by means of the stud-screws. As the lower plates were previously set horizontal, and the vertical axis of motion therefore vertical, the upper level will now be perpendicular to that vertical axis.

Bring the vertical arc to read zero by the rack and pinion motion: record the readings on the same staff placed in succession on each peg AB, after duly focussing in each case without parallax.

If these readings differ, the "virtual line of sight" is not level, in which case it must be tilted by shifting the diaphragm up or down by the diaphragm screws,—watching the effect on the readings on the staff through the telescope.

[*N.B.*—The diaphragm should be moved *up* if the reading on the further staff exceed that on the nearer and *vice versa.*]

Repeat the readings on the staff on either peg, and continue shifting the diaphragm until the readings become precisely the same.

[CAUTION.—Both before and after recording a reading on either staff the levels and vertical arc reading should be examined. If the level bubbles are not both at the centres, or the vertical arc not at zero, immediately after recording a reading, that reading should be rejected.]

RESULT.—The upper level axis and "virtual line of sight" will now be both horizontal, whilst the vertical arc is at its zero, so that in future a zero, reading on the vertical arc with the upper level bubble at the centre *will indicate the horizontality of the "virtual line of sight."*

52. The **transit** theodolite may be considered to consist of four main parts as follows:—

(1) The lower frame with socket head and three* footscrews F F F (see fig. 32) also C_1 lower plate clamp and T_1 lower plate tangent or slow motion screw.

* The three footscrew pattern instrument is considered in this book as it is the only pattern used in India and has one or two decided advantages over the four screw pattern in that it is more easily handled (one hand on occasions being sufficient) and because there is little or no strain on the axes.

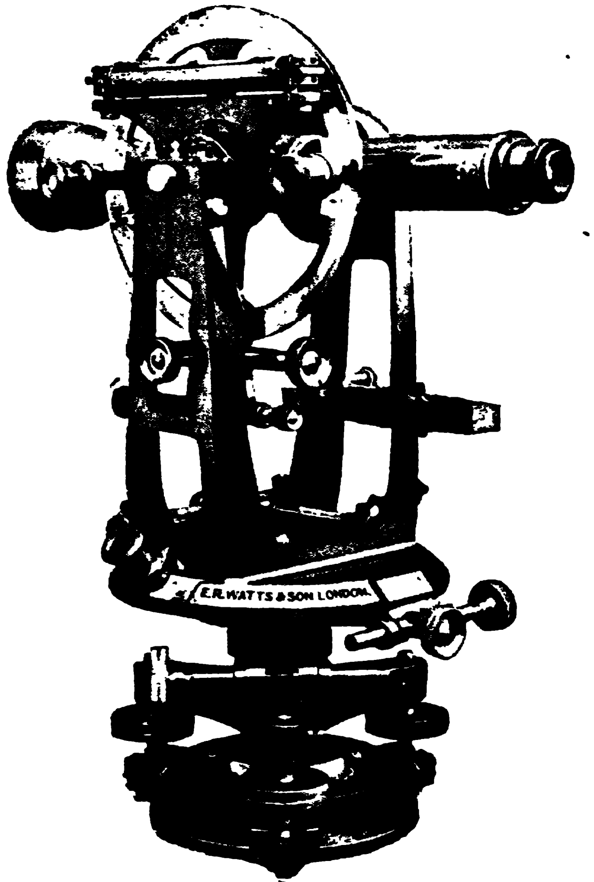
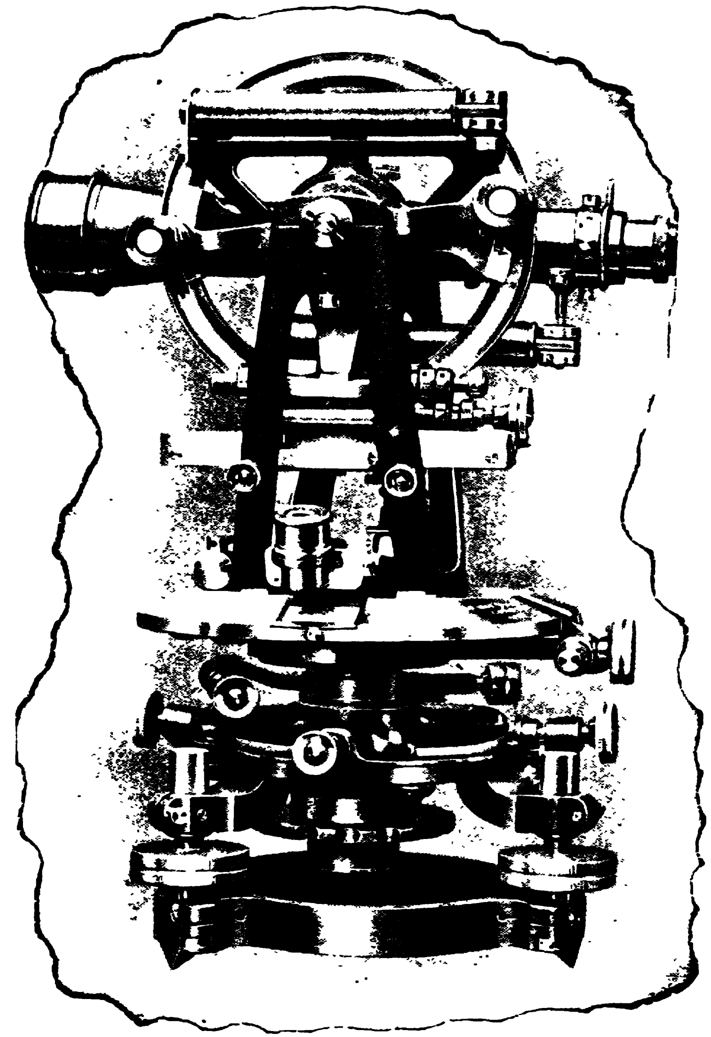


Fig. 33.

Fig. 33A.
Transit Theodolite.



Showing two bubbles for vertical arc and with traversing head.

(2) The lower plate or limbs with primary circle with its outer spindle which fits into the socket of lower frame.

(3) The middle part or upper plate with standards and verniers with spindle fitting into the lower plate, C_2 clamp for upper plate, T_2 tangent or slow motion screw for upper plate, B S bubble tubes (or levels) with adjusting nuts.

(4) The upper works consisting of telescope with fittings, such as the primary scale of the vertical arc, focussing arrangements for lenses, diaphragm &c., also a plate to which is attached verniers. B. N. bubble (vertical arc bubble or level) and stud or antagonistic screws V, (in the fig. 32 the antagonistic screw arrangement is a single screw working against a buffer spring). To this arm is fixed the vertical arc clamp screw C_3 and slow motion screw T_3.

Note.—The vertical arc bubble is, in diagram, fixed to the plate carrying the verniers, but in some theodolites it is fixed on the telescope and yet others have two bubbles one on the telescope and one on the vertical arc, vide fig. 33A.

Consider now the movements of the different plates on their axes or spindles. Let C_2 and C_3 be clamped and C_1 unclamped, then parts 2, 3 and 4 as one piece can be revolved horizontally on the outer spindle working in the socket.

Let C_1 and C_3 be clamped and C_2 unclamped then parts 3 and 4 as one piece can be revolved horizontally on the inner spindle working in the outer spindle.

Let C_1 and C_2 be clamped and C_3 unclamped, then the telescope only can rotate in its own vertical axis.

Finally clamp C_1 C_2 and C_3 and turn screw V and it will be noticed that none of the verniers will register any difference of reading and yet the upper level B. N. and the line of sight through the telescope will be affected and this movement is an important one to notice when the vertical collimation adjustment is taken into consideration.

53. **Permanent Adjustments.**—For horizontal and vertical collimation also for horizontality of diaphragm and parallelism of the vertical axis of a transit theodolite.

It is advisable in all theodolites where possible to keep the diaphragm or reticule in the optical axis of the telescope so that the line of sight shall pass through the centre of the lenses that is that the bubble on the vertical arc should be adjusted and made parallel to the line of sight and that the diaphragm should remain as placed by the maker. Some theodolites are

fitted with two adjusting screws only for the diaphragm, those for the adjustment of horizontal collimation error, so that in such patterns the vertical collimation must be done on the upper level.

(1) **Levelment of plates.**—(*a*) Place the lower level or bubble over two footscrews and with these two footscrews bring the bubble to the centre; turn the telescope through 90° when the bubble will be at right angles to its first position and bring it to its centre with the third footscrew only. Repeat this *temporary* adjustment till the bubble remains in the centre in these two positions only.

(*b*) **To adjust the lower bubble.**—With the bubble axis at right angles to two footscrews (in the second position as above) brought to its centre by the third footscrew only, turn it end for end, that is, revolve the instrument through 180° and any divergence will be double the real error in horizontality; correct half by the third footscrew and half by the capstan head screw attached to the bubble. Repeat and correct over these two positions till the error has been dispersed. Next place it over the other two footscrews and correct if necessary by these two footscrews only. The level should be now in perfect adjustment.

The reason for *adjusting* by one footscrew only is that the motion is an even one whereas with two footscrews the motion of the hands in turning may be unequal thus lowering one end more than the other.

(*c*) Since the level on the vertical arc is more sensitive, usually ground to 10 secs to the lower level of 20 secs, it may possibly happen that the small error unnoticed in the lower level is appreciable in the upper and therefore to put the instrument into perfect level adjustment it is preferable to adjust from the greater to the less or from the more sensitive level to the less sensitive one. Therefore after temporary adjustment (*a*) given above, place the upper level over one footscrew that is, the telescope will be found to be pointing in a line over one footscrew and with the antagonistic screw or screws V bring the bubble to the centre of its run. Turn the telescope horizontally through 180° when the bubble will occupy an end for end position over the same footscrew. Any divergence is twice the error and half is corrected by the antagonistic screw and half by the footscrew. Repeat in these two positions till corrected. Next place the bubble parallel to the other two footscrews and any divergence correct by these two footscrews only since any bubble error has been already corrected. The bubble should now remain in the centre of its run in any position of the upper plate. The reader will realise that if the lower plate levels are not now correct that the error exists in the axis of the bubbles and not in the axis of the

instrument; any divergence correct by the capstan head screws attached to the bubbles.

The above has been given at some length since it is often not understood in triangulation and ordinary star observations for time and azimuth why the upper level refuses to keep a medial position and an instrument undergoing a test for vertical collimation adjustment and with which many observations for vertical angles are to be made as in some classes of work it must be put through the adjustment for bubble axes vide (c).* An instrument used for traversing need only be put through adjustment (b) and ordinarily through (a) as a small error in horizontality will make no appreciable difference in horizontal angles. Finally in connection with the above the reader will see later that observations on two faces eliminate collimation error and that any divergence of the vertical arc bubble on each face can be recorded and allowed for (see appendix Part II).

In the plate at screw V there is a second screw just visible and this screw is intended to facilitate the operation of the levelment of the vertical arc at each set up as it regulates the distance of the threads on the antagonistic screw from the bush spring so that when the lower plates are levelled the vertical arc bubble should return to its medial position when the spring is released.

54. **Horizontal collimation.**—Clamp the lower plate by C_1 and with the upper plate intersect some defined object such as a rod or finial by clamping C_2 and using the slow motion screw T_2. Let the instrument be on face *left* that is, with the vertical arc to the left as the observer is looking through the telescope. Read the horizontal verniers and let the mean be 120° 16′. Unclamp C_2 rotate telescope vertically and point it again at the object when the instrument will be on face *right*. Clamp C_2 and intersect object by T_2 and let the mean reading be 300° 20′. There is thus a horizontal collimation error of 4′ which must be dispersed. Set the verniers to the mean reading that is to 300° 18′ on face right and the wires will no longer be on the object; bring the wires on to the object by the screws attached to the diaphragm by loosening one first before tightening the other. Change face again and check result. It is not possible to have no collimation error since the graduation of the plates if unequal will upset it and there is also no need for absolute dispersal of error if observations are made on both faces; in fact many surveyors prefer a small collimation error as it prevents them being biased in their readings.

* It will be seen hereafter that in case of an axial error in a footscrew this adjustment should not be rectified during observational work.

55. **Vertical collimation.**– With a level staff (*a*) when the bubble is fixed on the telescope (*b*) when it is attached to the vertical arc.

(*a*) In the case of the bubble being attached to the telescope set the verniers to 0°0′ and examine bubble which should be in the centre if the first adjustment has been properly done. With the instrument on face *left* (the bubble will be on top of the telescope) read to a staff and let the reading be 4·56. Change face when the bubble level will be underneath the telescope and it must be taken for granted that when the verniers are set to 0°0′ that the bubble will be in the centre. Again read the staff and let the reading be 4·60. Change face again that is bring the instrument back to face *left*, set the verniers to 0° when the bubble is again in the centre and *either* move the diaphragm so that the horizontal wire reads the mean viz., 4·58 *or* with the stud screws V make the wire read 4·58 and since the stud or antagonistic screws have been touched the bubble will no longer be in the centre, therefore, bring it back with its own bubble nuts B. N. The latter method is preferable since by altering the diaphragm once for horizontal and then again for vertical collimation there is a possibility of one vitiating the other.

(*b*) When the bubble is attached to the vernier arc the same procedure is carried out with this advantage that on the *right* face the bubble being on the vertical arc it does not become inverted and can be checked for medial position.

56. **Vertical collimation.**—By observing two natural objects, with both types of instruments. Select any defined distant object about 5° above the horizon and on face *left* intersect the object and let its mean vertical reading be 8° 52′. Next change face and on face *right* reintersect object and let its mean vertical reading be 8° 50′ checking the bubble on both faces.

There is thus a vertical collimation error of 2′ and the mean reading will be 8° 51′.. Return the instrument to face *left* and set the verniers to the mean reading 8° 51′ and as the object will not be now on the horizontal wire manipulate the diaphragm till the wire intersects *or* by means of the antagonistic screws intersect the object and when the bubble level is attached to the vertical arc correct it by means of its adjusting screws BN and when the bubble is attached to the telescope make the verniers first read 0°0′ and then correct it.

57. **Horizontality of diaphragm.**—This adjustment should really be made before collimation is taken in hand and though it is not often

necessary yet it should be checked. Owing to the diaphragm screws working in slightly larger holes or slots for the purpose of rotating the diaphragm in its own axis a very small quantity, it is posible by loosening the 4 screws that the diaphragm leaves its true position with respect to the horizontal and vertical wire, that is, it takes on a slight " slew." When the diaphragm has been entirely removed for rewiring of course it is most necessary that the following test is made. First perform the adjustment for levelment and turn the telescope to some mark on a wall or tree or evén a level staff and clamp the vertical arc and with either horizontal slow motion screw rotate the instrument from one extreme field of view to the other; if the horizontal wire does not cut the mark throughout its entire travel then it requires adjusting and this is done by slightly tapping up or down one of the horizontal diaphragm screws after loosening them. The student should notice that without this test he must confine himself entirely, in intersecting objects, to the intersection of the cross wires.

58. **Parallelism of the vertical axis.**—This adjustment is not always possible with the smaller class of instruments as the necessary screws are not fitted (see PP in plate). The adjustment is made on the standards for the transverse axis of the telescope so that the telescope will transit on a perfectly plumb line. Direct the telescope, after the adjustment for plate levels has been made, to a point on a clearly defined object at a considerable elevation, and by means of either tangent screw T_1 or T_2 bring the intersection of the diaphragm wires exactly to bear on that point; then depress the telescope without touching either tangent screws to a point as far below the first as possible and note exactly the spot at the intersection of the crosswires. Turn the instrument 180° transit the telescope that is, change face and again intersect the higher point and depress telescope and if the cross wires intersect the lower point the transit axis is horizontal; but if the lower point is not intersected by the cross wires, correct half the apparent error by the capstan screw P and direct the telescope again to the higher point and note the new position when depressing the telescope. If there is still an error when the instrument is again turned 180° the above operation must be repeated. In the more refined instruments a *striding level* is fitted in the box to test the horizontality of the transverse axis.

It is taken for granted that in the adjustment for collimation &c., or whenever an object is intersected that the temporary adjustments for focus and parallax have been made (see para. 60).

59. **The Method of observing with the Theodolite.**—The surveyor having satisfied himself that the theodolite is in adjustment can

now begin his observations. The adjustments just described are not necessary every time the instrument is set up but only now and then when the surveyor may have reason to think the instrument has been shaken by some means. It is well, however, before beginning a day's work, to see if the adjustment of the levels is correct or not, as it is soon looked to, and will often save a great deal of vexatious repetition.

Temporary adjustments to level the Instrument.—This operation is necessary every time the instrument is moved to a fresh position, and is performed in the following manner:—The instrument being placed more or less over the station mark it is approximately levelled up by means of the legs of the stand. It is next carefully centred over the mark by means of the plumbob and then the true levelment must be completed by the footscrews, (FF see plate):—that is that the *temporary* adjustment for levelment must be made by placing the lower level over two footscrews bringing the bubble to the centre by turning the two footscrews evenly either both inwards or both outwards. The left hand is usually the master hand with footscrews and the direction in which the bubble will travel will be the direction of turn given by the left hand. Next bring the bubble over the third footscrew and repeat till perfect. If the permanent adjustment previously explained in 63(*b*) has been properly done then two or at most three repeats should be sufficient for all purposes of traversing when the vertical arc is rarely used but if the instrument is being used for triangulation then the upper level being the more sensitive should be adjusted first when the lower levels will agree if the permanent adjustments have been properly made. Some old and worn instruments often refuse to remain level in every position of the telescope and time should not be wasted in trying to make such instruments do so and yet for certain classes of work they will give excellent results.

60. **Focus and Parallax.**—To intersect any object, first obtain a clear image of it by the focus screw at the side of the telescope. Then move out the eye-piece until the cross wires can be seen distinctly. To do this, hold the *socket* of the eye-piece firmly with one hand, and move the eye-piece with a gentle screwing motion with the other. Do not pull the whole instrument by the eye-piece by using one hand only, as it is often stiff. Then by means of the focussing screw move the object-glass (slightly) until the object is clearly seen, and on moving the eye about, the image of the objects will cease to move off the intersection of the wires or to have no fluttering and undefined appearance. The explanation of this is as follows:—a picture of the field of view is formed in the telescope, and until it concides with the plane of the wires this motion will take place; just as

looking out of a window, the position of the bars with respect to the landscape changes according as we change our position ; but if the landscape was painted on the glass (*i.e.* was in the same plane as the bars) this would not be the case. By moving the object-glass in and out, or as it is called " focussing," the image is brought on to the plane of the cross wires and if the wires become slightly indistinct or move over the object the eye-piece must be readjusted and so on, that is parallax must be dispersed so that no wobble of the wires on the object is visible. The dispersal of parallax is most important.

61. **To observe an angle.**—By means of the clamp C_2 and its tangent screw (*see Fig.* 32) set the vernier, marked A on upper plate, to 360° on lower plate, then turn the lower limb round, and with the lower clamp C_1 and tangent-screw, T_1 fix the cross-wires in the telescope on any object. Then loosen the upper clamp C_2 and turn the upper limb round, fixing the cross wires by the same clamp and tangent-screw on any other object; the angle subtended can be then read off on the instrument.

62. *Another method.*—Do not set the plates together at zero, but clamp the lower horizontal limb firmly in any position, and direct the telescope to one of the objects to be observed by turning the upper plate, moving it till the cross-wires and object coincide; then clamp the upper limb and by its tangent-screw make the intersection of the wires nicely bisect the object; now read off the two verniers, the degrees, minutes and seconds of vernier A, and the minutes and seconds only of vernier B, and take the mean of the readings, thus :—

$$A = 142° \; 36' \; 30''$$
$$B = 142° \; 37' \; 0''$$
$$\text{Mean} = 142° \; 36' \; 45''$$

Next release the upper plate, and move it round until the telescope is directed to the second object (whose angular distance from the first is required), and clamping it make the cross-wires bisect this object, as was done by the first, again read off the two verniers, and the difference between their mean and the mean of the first readings, will be the angle required.

63. It is contended by some surveyors that it is best to work with the zero line of the lower plate pointing North and South, so that all readings to any objects are their magnetic bearings. Thus the two plates being clamped together as in first method, the lower plate is set to coincide with the magnetic compass and clamped. The method of observing after this is as in the second method. The only difference being that instead of " any position " the lower plate is due North and South.

64. **To repeat an angle.**—Leave the upper plate clamped to the lower, and release the clamp of the latter; now turn the lower plate, i.e. both together round towards the first object, till the cross-wires are in contact with it; then clamp the lower plate firm, and make the bisection with the lower tangent-screw. Leaving it thus, release the upper plate, and turn the telescope towards the second object, and again bisect it by the clamp and slow motion of the upper plate.

This will complete one repetition, and if read off, the difference between this and the first reading will be double the real angle. It is however best to repeat an angle four or five times; then the difference between the first and last readings (which is all that it is necessary to note), plus 360° for each full revolution divided by the number of repetitions, will be the angle required.

65. **The magnetic bearing** of an object is taken by simply reading the angle pointed out by the compass-needle, when the object is bisected: but it may be obtained a little more accurately by moving the upper plate (the lower one being clamped) till the needle reads zero, at the same time reading off the horizontal limb; then turn the upper plate round to bisect the object and read again; the difference between this reading and the former will be the bearing required.

66. In taking angles of elevation or depression, it is scarcely necessary to add, that the object must be bisected by the horizontal wire, and in preference at or near the intersection of the wires, and that after observing the angle with the telescope in its natural position it should be repeated with the telescope turned half round in its Y's, i.e., with level uppermost, in case of the Y theodolite; or in case of the Everest and transit theodolites with the "face reversed," i.e. with the horizontal axis reversed end for end in its bearings: the means of the two measures will neutralize the effect of any error that may exist in the line of collimation provided that the bubble is in the centre on both faces.

The altitude and azimuth of a celestial object may likewise be observed with the theodolite, the former being merely the elevation of the object taken upon the vertical arc, and the latter its horizontal angular distance from the meridian (see also end of para. 93).

67. **How to level with a Theodolite.**—Place the instrument *medially* between the stations whose difference of level is required. Perform the temporary adjustments. Tighten the stud screws and clamp the vertical arc in some convenient position not necessarily horizontal. Read the levelling staff placed on the pegs successively by unclamping the lower plate. The difference of the readings will give

the true difference of level notwithstanding instrumental errors. The upper level is not used at all. The arm carrying the verniers does not revolve. Hence if the instrument is in adjustment as regards the virtual line of sight, the line joining the zeros of the vertical verniers will be horizontal when the upper bubble is at the centre of its run (see adjustments paras. 55 and 56) but the zero will seldom coincide and as shown above it is not really necessary that they should.

68. **Definitions of the terms Right and Left Swing and setting.**—A **swing** is a continuous rotation of the telescope horizontally beginning and ending with a zero. Several angles may be observed in the case of a *swing*. It is clockwise or counter-clockwise, commonly known as right or left swing.

A **setting** is the exact division on the limb or arc to which A vernier is clamped at the commencement of a round of observations. The "zero" includes a pair of settings on different faces, right and left, and may be 0° and 180,° 60° and 240,° 90° and 270° &c. If the first zero is 0° and 4 zeros are to be observed on, then the next zero is found as follows:— $\frac{360^\circ}{\text{No. of verniers} \times \text{No. of zeros}}$ Thus with 2 verniers and 4 zeros the next zero will be 45° and the 4 zeros will be 0°, 45°, 90° and 135°; with 3 verniers and 8 zeros the next zero will be 15° &c., with 2 verniers and 2 zeros the zeros will be 0° and 90°.

69. **Errors in using a theodolite.**—There are many errors and a surveyor must have a fairly competent knowledge of their varieties before he can get an intelligent grasp of the means employed, as far as is possible, to eliminate them. Errors might be conveniently placed under the following heads (a) Error of manufacture and errors in the instrument through non-adjustment and usage: (b) Errors of observation: (c) Local errors: (d) Errors of Record. Errors therefore are best treated under two heads, viz. Errors of instrument and the general sources of errors when using the instrument, and are as follows:—

(1) Diaphragm wires not vertical and horizontal and adjustments for levelment and collimation.
(2) Shake and settling of the stand or tripod.
(3) Errors of parallax and of the focussing slide.
(4) Eccentricity of circle.
(5) Errors of graduation and drag on verniers.
(6) Worn threads of slow motion screws.
(7) Bad centering of instrument.
(8) Bad centering of object observed to.

(9) Poor focussing.

(10) Undue pressure in clamping.

(11) Vibration under strong winds and temperature changes, causing unequal refraction.

(12) Using the wrong tangent screw for horizontal angles.

(13) Placing the hand on the stand when observing.

(14) Using an instrument which has become clogged with oil and dirt or has been previously damaged.

(15) Swinging the upper plate around by the telescope instead of by the standards.

(16) Bad intersections of object and incorrect reading and recording of values.

70. To treat with them in detail, errors under head :—

(1) Have been explained under adjustments (see transit theodolite adjustments) but it must be borne in mind that it is loss of time to try and dispose of collimation errors absolutely.

(2) The stand when set up should have its clamp nuts thoroughly tightened and the tripod should be well and firmly set into the ground. There should be no possible shake.

(3) Parallax should be properly dispersed and the focussing slide should be examined to see, when it is moved in and out, that an object is stationary on the wire and does not appear to wobble as it comes into and goes out of focus, from one side to the other. There may be an error in fitting of the tube and grinding of the lenses. Such errors of slide and lenses are best corrected by an instrument maker. The ratchet and wheel of the focussing arrangement should be treated occasionally with a dressing of beeswax.

(4) *Eccentricity of circle.*—This is due to the axis of the horizontal vernier or of the upper plate and the axis of the limbs not coinciding and the result is that although the zeros of the verniers may not be exactly 180° apart and the graduation of the instrument perfect, there is a variable difference of reading over different portions of the plate. The error in the zeros of the vernier would give a constant difference and the mean reading of the two would disperse the error.

The error in eccentricity is usually so small that it can be neglected, but the diagrams will show how an error is introduced which is variable and not a constant.

Fig. 34.

Diagram 1. *Diagram* 2.

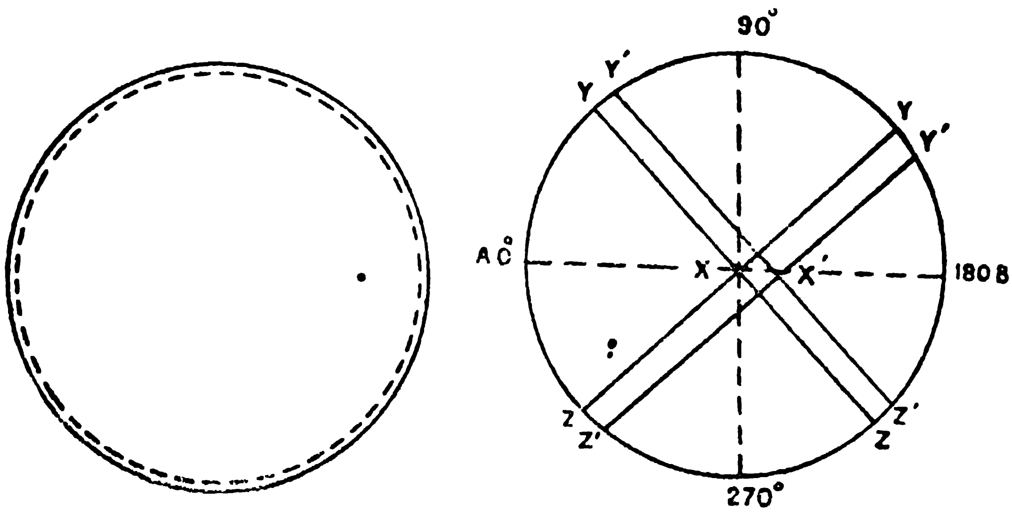


Diagram I Fig. 34 shows no eccentricity as the centres are coincident.

Diagram II Fig. 34 shows eccentricity as X is the centre of the limb and X′ the centre of the vernier or upper plate axis.

Let the two centres be in a line with the 0° and and 180° of the limbs. Then the following conditions will arise :—

At 0° and 180° there will be no error.

At 90° and 270° there will be a maximum error.

Between 0° and 180° the vernier Y′ will read too much.

Between 180° and 360° the vernier Z′ will read too little.

Error dispersed by using several zeros.

(5) *Errors of graduation.*—In most modern instruments the errors of graduation are reduced to a minimum, but what errors exist can be dispersed by observing on different parts of the limb for each station or what is technically known as a different setting of zero. The error of drag or the slight adhesion or friction of the vernier on the limb which causes it to be held back is neutralised by observing stations on a forward and also backward swing (left and right swing).

(6) Worn threads on the slow motion screws specially when such screws are acting against a spring, cause a slip of the plate and this may happen between the intersection of the object on the wire and the reading so that the reading may be as much as 10 minutes incorrect.

The screws should be rethreaded or if this is not possible at the time, the screw must be used on a good portion of the thread and the intersection should be again examined after the reading has been recorded.

(7) and (8) Great exactness in centering of instrument is necessary and especially in mining and tunnelling work where meridians above ground have to be transferred down a shaft, and a personal interest in it should be taken so as to convey to other members of the party at work what is expected of them when they are sent out on independent work to set up signal flags and helios.

(9) On triangulation poor focussing means that the focus is not at infinity, as it should be for more or less distant signals and if there is any error in the slide and draw tube altering the focus must bring in the slide error if any exists.

(10) Clamps should be tightened with just sufficient pressure to make them hold which is usually very little indeed. Any undue pressure might lead to one part of the vernier plate being strained and to a slight jump when the tension is relaxed. A delicacy of touch in handling instruments is a sure way of obtaining good results.

(11) Observations taken under adverse atmospheric conditions should be avoided if possible. A good intersection is impossible when the air is "boiling." Refraction is greatest in the early morning and late evening and least between the hours of 11 a.m. and 3 p.m., and 1 p.m. is the best time to take vertical angles on triangulation.

(12), (13), (15) and (16) Are either mistakes or bad habits.

(14) The instrument should be first tested for adjustments and if it fails to come up to the standard of accuracy required for the particular work in hand it should be returned for repairs. The part most liable to injury is a footscrew and in a good instrument when the telescope rests over a footscrew and on that screw being turned the line of sight should move up and down vertically; if it moves also to one side it is in poor order but still will give good results as long as after the levelment of the bubbles the footscrews remain *untouched* throughout the observations taken for **horizontal** angles. This is important to remember.

71. **Useful hints on the use of the Theodolite.**—A few hints on the use of these delicate instruments are here added.

1st. They must not be handled roughly. In taking them in and out of the box, it should be done with the greatest care, not knocking them

against the sides of the box or forcing them into their positions within it; the boxes are so constructed, that the instrument fits exactly into its own place, and unless it settles down of itself, forcing it will throw the instrument out of adjustment. If not already done, the sides of the box should be marked to show the proper positions of the ends of the telescope, and the lower plate clamping screw, and perhaps the position of the verniers as this turns independent of either plate. This allows of the instrument being arranged outside the box and put in at once. After placing the instrument in the box all clamps should be tightened, and springs, such as those attached to micrometer screws released.

2nd. In using the instrument it should always be handled by its substantial parts, not twisted round by the eye-piece, as careless surveyors constantly do; and before attempting to turn any part, care should be taken to see that the clamp is loose and it is free to turn. A little attention to do the proper thing at first makes it a habit and just as easy as the wrong one.

3rd. Always throw the needle off its centre by the stop fixed on one side of the box, when the instrument is not in use, as the constant playing of the needle wears the pivot upon which it is balanced, and on the fineness of this point depends the accuracy of the bearing. This is equally applicable to the Prismatic Compass.

4th. It may not be superfluous to remind surveyors that although instruments are adapted for use in the field, the less their various axes, screws, &c., are worked the longer they are likely to last in an efficient state. The setting-up and adjustment should, therefore, be effected with the least possible amount of motion and if the instrument is to be carried without being replaced in its box the clamps must be tightened to prevent their axes swinging and taking up unequal wear.

Micrometer screws should require but a touch after the clamps have been tightened, and the levelling of the instrument should be done as nearly as may be by moving the legs before using the footscrews.

5th. If any part of an instrument be found to work stiffly, the cause should be ascertained before proceeding further, and removed. A single grain of sand getting in between a pivot or axis and its socket will often jam them firmly together, besides making a spiral score round them, not easily effaced. Want of oil invariably causes wearing in those parts subject to constant friction. Good neatsfoot and salad oil are the best lubricators, and in their absence " til," well clarified by simmering over a slow fire, and straining through fine flannel (the process to be repeated until the oil is

colourless, or nearly so). Clock oil is obtainable in most bazars and is the best. It should be applied in the *smallest possible* quantity, and *only to the parts exposed to friction*. None on any account to be applied to the *footscrews*, nor to cog-wheels or micrometer screws. Any oozing out at joints or shoulders should be carefully wiped off. Every part of an instrument exposed to the air should be kept perfectly dry; and before commencing work, should be carefully freed from dust by a camel hair brush *not* with a cloth.

6th. Always keep the instrument as clean as possible, see that there is a good outer padded cover, and fill the inside of the box and the top with loose cotton wool wrapped in paper so that the instrument will again be protected. Have stout straps fixed on to the boxes to carry them by and always have them carried by men, not in carts. Wipe all dust off carefully both on commencing and leaving off work. The instrument will repay your care, and it keeps you in good temper to have it working easily. On the care a surveyor takes of his theodolite, depends much of the accuracy of his work; if he neglect and be careless about the former, he will one day have to lament over the accumulated errors of the latter.

Instruments not in use and not expected to be in use for some considerable time should have the lid opening and any cracks in the wood work of the box pasted over with slips of paper to prevent dust lodging on the instrument. Where dust storms are prevalent this is a very necessary precaution to take.

7th. Object-glasses often become clouded; and if the cloudiness is not removed by cleaning both faces of the lens, the glasses of which it is composed should be separated, and the inner surfaces carefully cleaned; if this be not done, the cloudiness will probably become permanent, and can only be removed by repolishing by the instrument maker. Soft wash leather, or an old silk handkerchief, carefully freed from grit or dust, will be found the best material for cleaning either the glasses or finer portions of the metal work. If the leather or a silk handkerchief be moistened with spirits of wine or liquor ammonia, the rubbing will be more effectual in removing cloudiness from glasses. Lenses when taken to pieces must be carefully replaced as found, and the whole glass must be screwed back into the telescope as left by the maker. Some makers cut marks, one on the ring holding the glasses and one on the telescope rim, showing when the position is correct.

8th. The cross wires, when not of platinum or floss silk, are best made of cobweb; the finest and cleanest are those found on bushes and

long grass; they can be attached to the diaphragm with Canada balsam, common lac dissolved in spirits, or any gum moistened with *diluted* spirits, or, in default of any of the above, with a little bees wax. The gum should be put lightly on the diaphragm, and the thread taken between the points of a pair of compasses gummed also to make it stick, and opened wider than the diaphragm. The thread can then be carefully laid on. Thin glasses with lines scored on them are now made. These are practically indestructible, but if made of inferior glass are liable to become obscured by a branching sea-weed like fungus, for which the only remedy is to get a new diaphragm-glass.

9th. The variation of the compass needle from the meridian in every instrument should be ascertained, either by actual observation according to any of the usual methods, or by comparison with some other instrument of which the variation is known, and recorded with the name of the place where it was observed on a paper pasted on the inside of the instrument box or case. Date also to be noted.

10th. To take an instrument to pieces for cleaning purposes it is necessary to unscrew all clamps and tangent screws, next to unscrew the lower axis spindle screw. The plates will generally be found to come apart in three pieces. For ordinary cleaning there is usually no necessity to go further, but if the vertical arc axis requires looking to, the small screws keeping the plates together will have to be taken out and they must be returned to their correct positions. Some makers dot screws and holes so this may be done. Any old oil and dirt should be cleaned off with kerosine and then clock oil used and wiped off. Too much oil is as bad as none at all and the slightest smear is sufficient. The graduated arc and verniers can be washed and cleaned with soap and wash leather and the engraving filled in by camphor black and oil rubbed in by the finger passed lightly over the silvered portion and allowed to dry and 24 hours afterwards gently wiped off. The edges of the verniers are sharp and soft and are easily burred if carelessly handled. Dust is always a greater enemy than damp. Except when cleaning the graduated limbs and verniers, when they need it, perhaps after a few years work, they should *never* be touched by the hand.

Since there is something to be said as to the choice of an instrument the pattern illustrated in fig. 33 is recommended as being suitable for engineering surveys and is priced at about £30 or less, in fact £30 should almost include the cost of a Zeiss pattern telescope. It comprises roughly of the following:—transit, 6 inch divided to 20 secs vernier reading, with stadia, traversing head for centering, spare bubbles, sun hood, spare

eye-pieces for astronomical work, in one or two pieces fitting in one box 24″ × 9″ × 8″ (see also para. 86).

72. **The Solar Attachment** (fig. 35) has come into great favour in America for all public land surveys as a means by which the telescope is set on the meridian, that is true meridian, in preference to a magnetic meridian. To thoroughly understand its principles the reader is requested to study the chapter on Astronomy Part II and when he has done so he will understand that when the solar attachment is placed on the telescope and if he were in latitude 45°N, and the telescope depressed so that the object end vernier reads 45° (colatitude) with the object glass towards the north that the eye end of the telescope will intersect the celestial equator and that the axis of the attachment will be parallel to the axis of the earth at the place (see plate). If the vernier of the *attachment* is clamped at 0° then the line of sight passing through the solar lenses would be parallel to the line of sight of the telescope and if the attachment is in adjustment when the sun is at one of his equinoctial points then on the instrument being rotated the sun will be focussed in the small square of the mirror. Now the sun's declination varies every few minutes so that an arc to include his full declination N. or S of 23° 27½′ is required and hence the arc and vernier of the attachment. The sun's declination and variation per hour for Greenwich, day by day, is given in the nautical almanac from which the declination for any hour at a place E or W of Greenwich is found. As the apparent sun (true sun) is being observed to, its elevation or altitude on account of refraction will be greater than its true altitude and thus it is necessary a few minutes before making the observation for meridian to roughly obtain his altitude and from the table of refractions and his calculated declination to correct to apparent altitude. At the foot of the attachment is the hour circle divided to 5 minutes of time and by rotating the attachment on its own axis the hour circle can be set to any time at which the observation is to be made. For example, let the standard time at the place be known. Correct this to local mean time and this again to Greenwich time of observation. In the nautical almanac look up the sun's apparent declination at Greenwich mean noon for the date of observation and correct the declination considering the sun's variation as given between the time of Greenwich mean noon and the Greenwich time of observation. (The variation per hour is given in a separate column in the N. A.) Having obtained the declination correct for refraction set the hour circle to the selected local time and by rotating the whole instrument the sun's image is focussed between the engraved lines on the mirror *when the line of sight through the telescope cannot occupy any other position but on the*

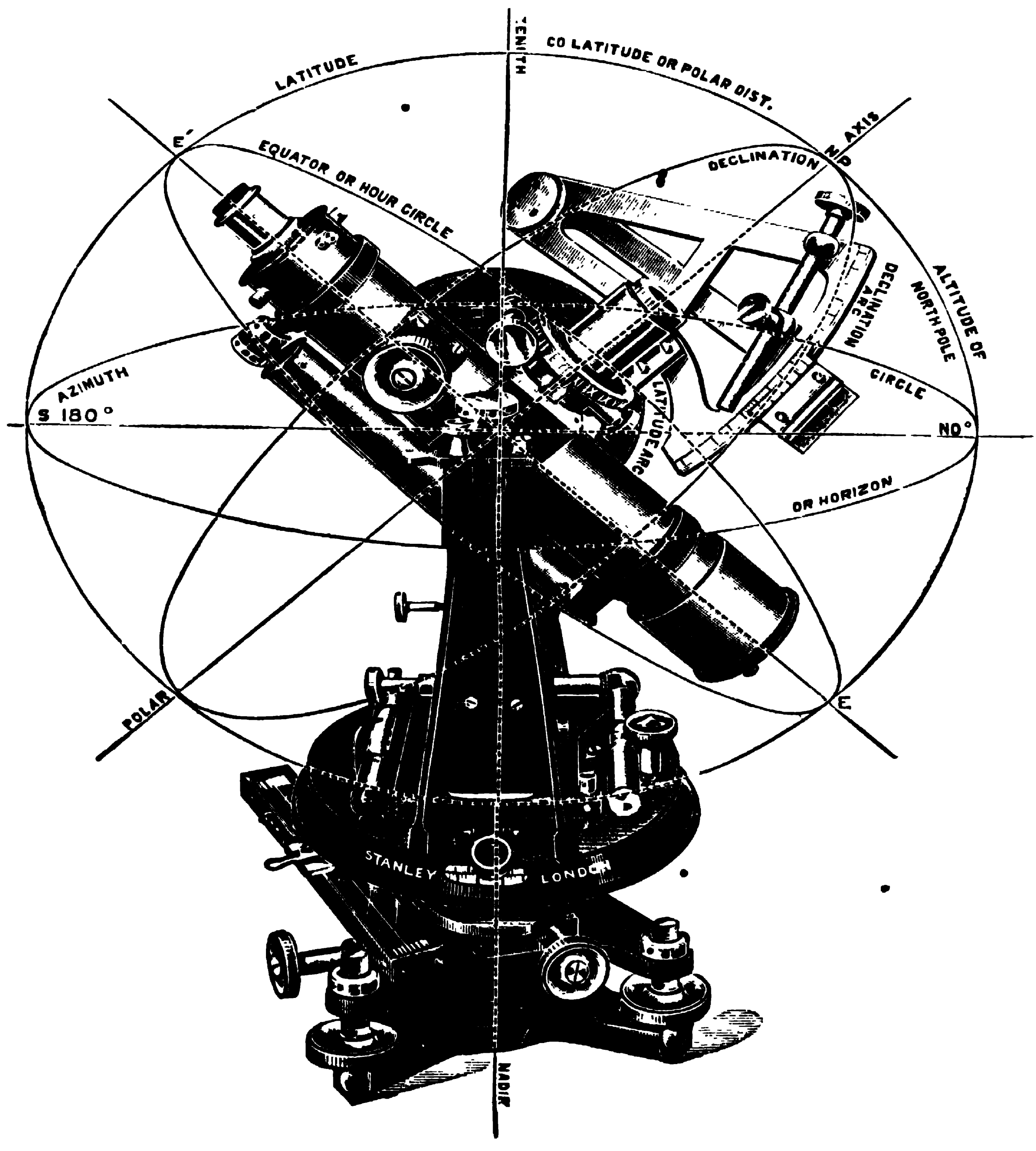
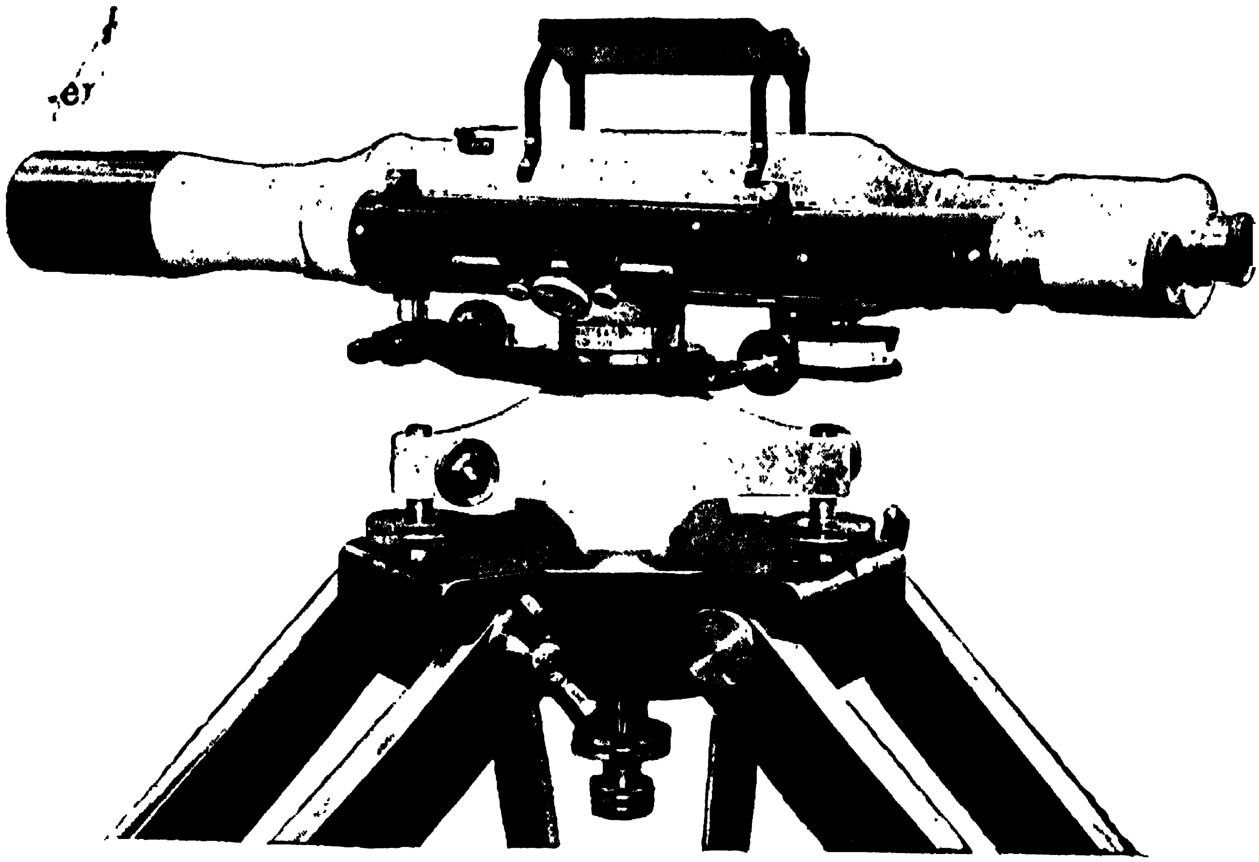
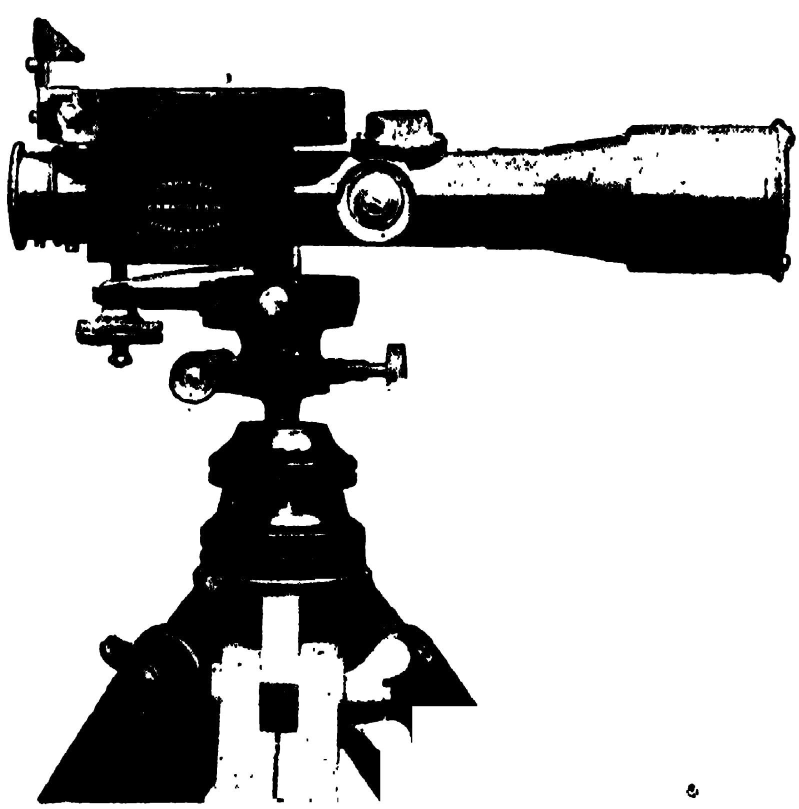

ZENITH
CO LATITUDE OR POLAR DIST.
LATITUDE
AXIS
N.P
DECLINATION
EQUATOR OR HOUR CIRCLE
E'
DECLINATION ARC
ALTITUDE OF NORTH POLE
AZIMUTH
S 180°
CIRCLE
N0°
LATITUDE ARC
OR HORIZON
POLAR
E
STANLEY LONDON
NADIR

Fig. 35

BINOCULAR PRECISE LEVEL.



RECONNAISSANCE LEVEL.



meridian. If the sun has a S declination then the attachment will be reversed or occupy an end to end position opposite to that given in plate. The upper plate of the theodolite should be clamped to zero and the lower plate unclamped and the instrument rotated till the sun is focused when the lower plate is clamped and if the upper plate is now unclamped and a reading taken to an object, the reading will thus represent the bearing or inclination of the object from true north. Observations to be reliable should not be taken within an hour of noon.

There is an improved pattern which is more accurate since it is fitted with a telescope and on transfrontier or reconnaissance work with the meridian fairly accurately found by this attachment an observation from two known stations would be sufficient to fix the point. Tables for refractions and declinations for use with the solar attachment are extant and simplify work considerably.

73. **Levels, their designs and adjustments.**—Designs in levels* are now practically confined to three types. *The Wye* or Y, *Dumpy* and the *prism or reflecting* pattern level.

Cushing's reversible level is of Dumpy form and its adjustments are almost the same as those of the Dumpy.

74. The **binocular** level or **precise** level, (see illustration) now used by the Geodetic Surveys, U. S. A. and by the Great Trigonometrical Survey of India is of a type which the engineer is not likely to use or need, as it is too delicate for rough work and requires a specially trained squad for it. The distinctive feature of this level is that the observer is able by a set of reflectors and prisms to read the bubble value at the same instant as the staff, and the level being binocular, both eyes are used. The line of collimation is independent of the vertical axis.

75. The **Wye or Y** level is so called because the telescope rests in Y supports and its permanent adjustments are as follows:—

See that the instrument is securely screwed home in its stand and that the tripod is quite firm and rigid; bring the footscrews F F to the centre of their run and roughly level by means of the legs and press the legs well in to the ground.

Place the telescope over one footscrew and bring the bubble into the centre of its run by this footscrew and clamp the instrument by the clamp C (see fig. 37).

(1) Twist the telescope, after first loosening the clips, to one side and then the other on its vertical axis. If the bubble moves then it shows

---

* Rough levelling instruments, such as clinometers, Abney level, De Lisle clinometer Ceylon Ghat tracer, &c., are not included in this category.

that the axis of the bubble and the axis of the telescope are not in the same plane. Adjust for lateral motion by the screws fitted for the purpose on the side of the bubble opposite to bubble nuts B.

(2) Reverse the telescope in its Ys. and if the bubble does not come exactly in the centre of its run adjust half the error by the nuts B. and half with the footscrew F.

Repeat the operation till the bubble remains in the centre, whichever way the telescope lays in its Ys.

(3) Revolve the instrument on its axis about 180° and if the bubble is not in the centre of its run adjust half the error by means of the Y. nuts Y. and half with the footscrew: then turn the instrument through 90° so that the telescope lies over the other two footscrews (if a 3 footscrew pattern) and correct any divergence by these two footscrews and repeat this operation till the bubble remains correct in whatever position the instrument is turned on its axis; the clamp screw C. will have been loosened.

(4) Now put in the clips and look through the telescope and see whether the wires of the diaphragm are truly vertical and horizontal that is whether the frame which carries the diaphragm glass or the frame on which wires are fixed has not been twisted. Select any object and gently rotate the instrument on its axis by the slow motion screw T and if the horizontal wire leaves the object then adjust it horizontally by a slight twist in the sleeve through which the diaphragm nuts D. work.

(5) Turn the instrument and clamp it on some well defined spot, disperse parallax, unclip the Ys. and note the exact spot intersected by the two wires. Revolve the telescope in the Ys. on its own axis half way round and if the object has moved laterally or in a horizontal direction correct half the error by the diaphragm screws D. D. giving lateral motion and half by the slow motion screw T. Revolve the telescope a quarter turn and correct the vertical wire in a similar manner.

Repeat this operation till the point of the intersection of the wires remains stationary when the telescope is revolved. Adjustment 5 can be made first, in fact some levellers prefer to make this their first adjustment.

The following will make the above clear. See figs. 38 and 39.

Adjustment 1 has been explained.

Adjustment 2 is to make the axis of the bubble parallel to the line of sight and axis of collars.

Adjustment 3 for the Y supports, so that the axis of the bubble is parallel to the level bar which is at right angles to the vertical axis of the instrument.

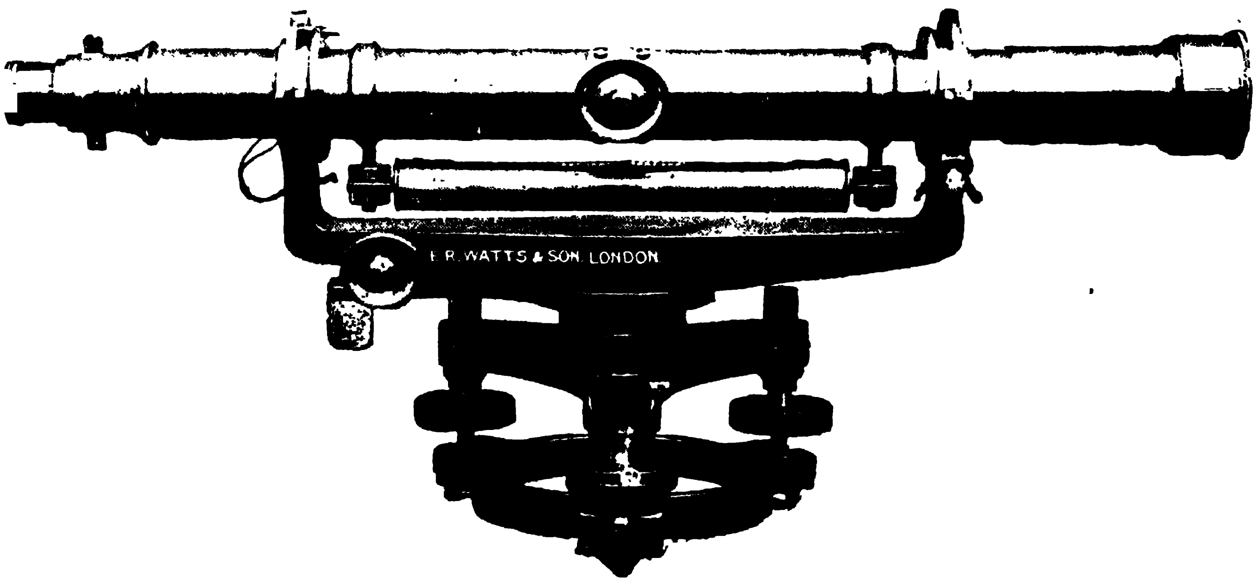


Fig. 36.

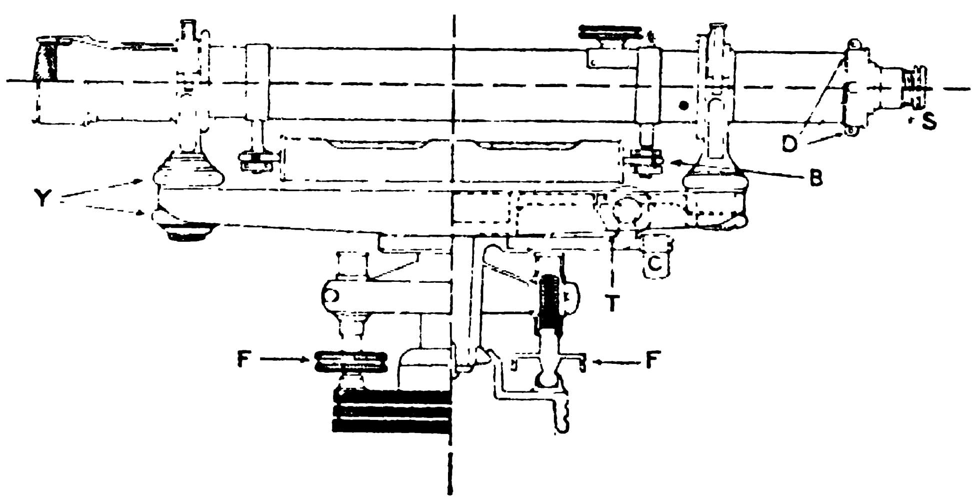


Fig. 37.

Adjustment 4 for the diaphragm ring so that the wires are vertical and horizontal.

Adjustment 5 to make the line of sight pass through the cross wires and the optical centre of the object glass.

Fig. 38.

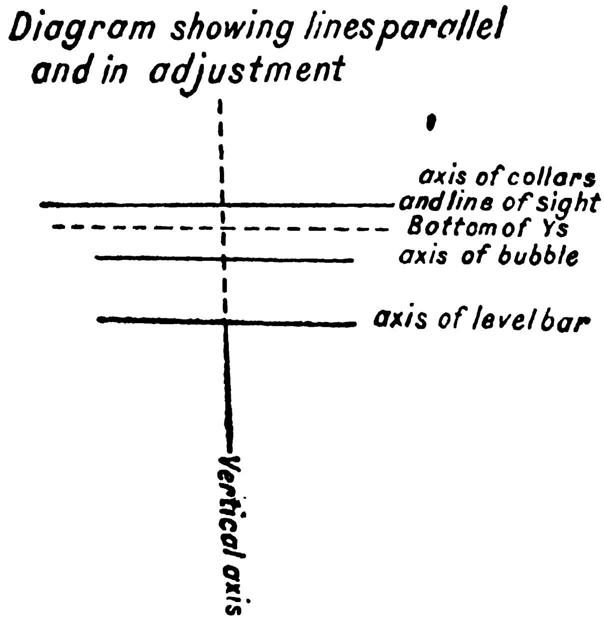
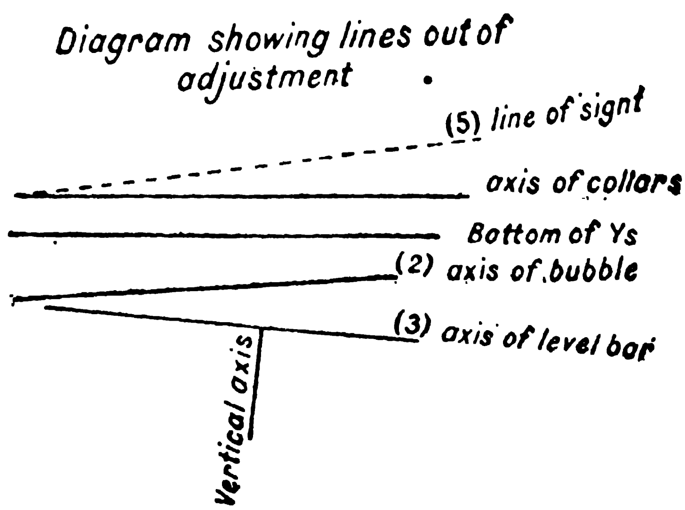


Fig. 39.



Again adjusting from the line of sight down to the vertical axis.

Adjustment 4 having been made for verticality of diaphragm adjustment 5 is made so that the line of collimation is coincident with the axis of revolution of the telescope in its Ys. In other words the line passing through the optical centre of the object glass and the intersection of the cross wires is made parallel to the axis of the collars.

Adjustment 2 is to bring the axis of the bubble parallel to the bottom of the Ys and in a perfectly made instrument, this means parallel also to the axis of the collars and the line of collimation

Adjustment 3 as before so that finally the line of sight is made at right angles to the vertical axis of the instrument.

This is known as the direct method of adjusting.

76. The **Dumpy level** is so called on account of its compact form (fig. 40).

The permanent adjustments are as follows :—

(1) To make the axis of the bubble at right angles to the vertical axis of the instrument. It is necessary that this adjustment is made before the adjustment for the virtual line of sight.

Place the bubble tube 1 over two footscrews SS and by means of these footscrews bring the bubble to the centre of its run. Next place the bubble tube at right angles to the first position or over the third footscrew (if it is a three screw instrument) or over the other two screws (if it is a four screw instrument) and bring the bubble to the centre of its run. Return to the first position and repeat these two operations till the bubble remains steady in the centre remembering that the telescope has not been turned end for end in the operations. This constitutes a *temporary* adjustment (see para. 59). The vertical axis of motion will now be *nearly* vertical and the bubble axis nearly horizontal.

(2) Now place the bubble tube over any footscrew and bring the bubble to the centre by that footscrew and then gently reverse the position of the telescope end for end; any deviation of the bubble will be twice the real error of perpendicularity. Correct half the deviation by the nuts at the end of the bubble tube by loosening one and tightening the other and half by the footscrew and repeat till perfect. The axis of the bubble has now been made truly horizontal. Place the bubble next over the other two foot-screws and correct any divergence by these footscrews only. The axis of the bubble is now at right angles to the axis of the instrument (compare para. 53 (*b*)).

(3) To make the line of sight parallel to the axis of the bubble and hence at right angles to the axis of the instrument. (Known as the peg adjustment or running a level line in the air.)

Set up the instrument exactly midway between two pegs on a fairly level piece of ground so that one footscrew will be directly in the line of the telescope when the telescope is pointing in a direction of the pegs. Bring the bubble to the centre of its run and observe a staff on one

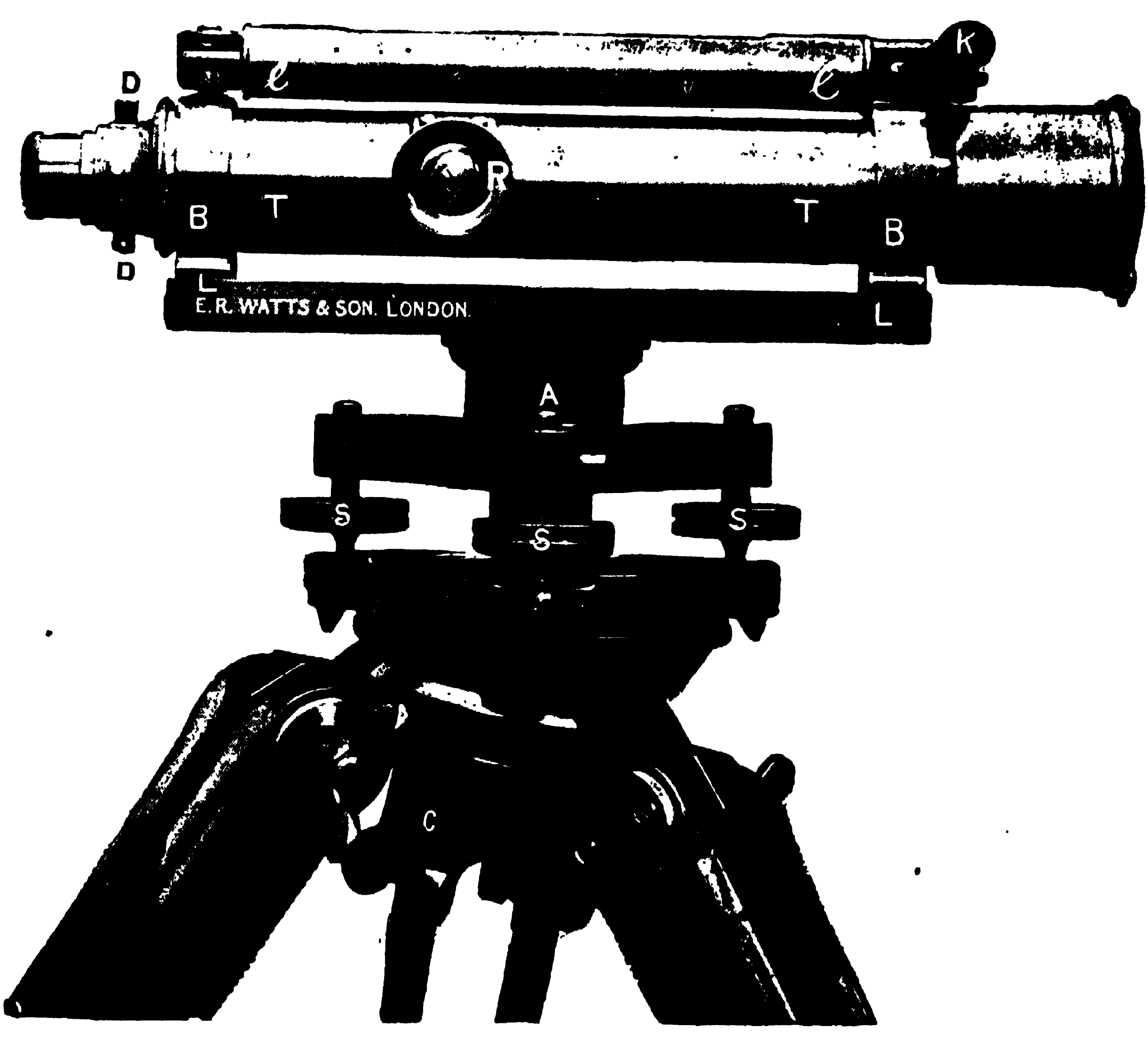


Fig. 40.

peg and record the reading. Next move the staff to the other peg and record the reading and tap down the higher of the two pegs till the staff readings on the two pegs read alike. The two pegs will be on the same level since any instrumental error is cancelled provided the bubble is in the centre of its run when the observations are made and the instrument is midway between staves (compare para. 49).

(4) Now take the instrument to a position in the same line as the two pegs either again between the two pegs or beyond one peg so that the distances between the pegs and instrument are unequal, the position beyond one of the pegs is the better one. Bring the bubble to the centre of its run and if the readings on the staff held on one peg and then on the other are not alike then the collimation or line of sight is not correct. To adjust the line *either* adjust the diaphragm by raising or lowering it so that the readings are alike in proportion to the distances, remembering that if the reading on the further staff exceeds that on the nearer it should be moved up and vice versa; *or* lower or raise the telescope by the pair of collimating screws LL* directly under it, till the horizontal wire gives the same readings on the staves when it will be found that the bubble will have left the centre of its run when it must be brought to the centre by the adjustment nuts for the bubble tube (see fig. 40.)

The adjustment by the collimating screws which are just under the telescope permits of the diaphragm being left just as the maker placed it and which should be, in preference, in the optical axis of the telescope.

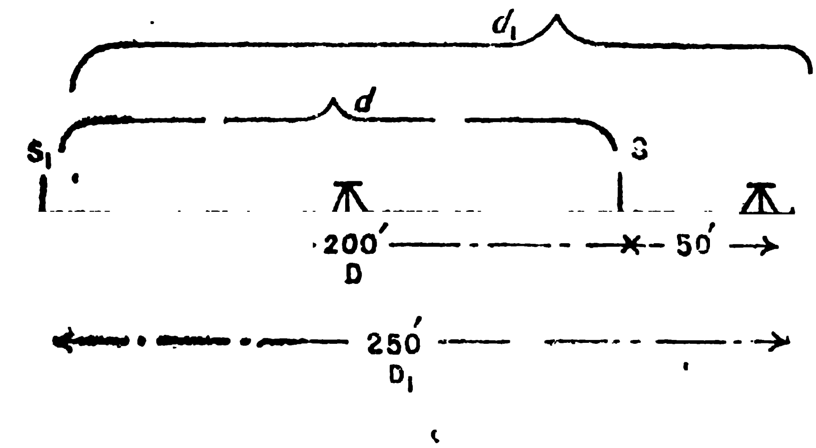
When the telescope is raised or lowered by these screws LL the bubble naturally will no longer be in the centre, but as the foot-screws are not touched when the bubble is brought back to the centre, it will then remain in the centre in all directions. If an instrument is not fitted with collimating screws then the diaphragm must be raised or lowered.

77. There is no necessity to obtain the same height for the two pegs, for instance let the instrument be placed midway between two pegs S & S_1 such that the distance D between them be 200 feet and the reading on S $=2{\cdot}81$ and the reading on S_1 be $4{\cdot}66$. The difference in height $1{\cdot}85$ is the true difference as the errors if any of the instrument are equal and opposite and therefore cancel.

Now place the instrument 50 feet beyond S so that it will be 250 feet $=D_1$ beyond S_1, and in the line of S & S_1. Let the readings on

* These collimating screws serve the same purpose as the antagonistic or stud screw in a **theodolite**.

Fig. 41.



S & S_1 be 4·80 and 6·83 respectively. Since the new difference is 2·03 it shows that the line of sight is not truly level. By similiar triangles the difference on S_1 will be $\frac{D_1}{D}$ $(d_1 - d)$ where d = the difference of the first readings viz., 1·85 and d_1 = the difference of the second readings viz., 2·03 $\therefore$ difference on $S_1 = \frac{250}{200}(2\cdot03 - 1\cdot85) = \cdot225$ and therefore the line of sight to be level will read $6\cdot83 - \cdot225 = 6\cdot650$ on S_1 and as a check $4\cdot80 - (\frac{\cdot225}{5}) = 4\cdot755$ as the reading on S.

78. Another method and probably the better method is to set up the instrument say close up to peg S so that the staff held on S will nearly touch the eye end of the telescope when the object end points to S_1. Level up the instrument and read the staff on S by looking through the *object* end of the telescope the true *height* of the axis of the telescope or line of sight on S will be the central graduation as seen. Send the staff to S_1 and read it noting that the bubble has remained in the centre of its run.

If the instrument is in adjustment the difference of the staff readings will be the difference of heights of the two pegs ; if the instrument is out of adjustment then the difference of the staff readings plus or minus the error in adjustment will give the true difference in elevation of the two pegs. The instrument is next set up close to the peg S_1 and under the same conditions as at S the staff is again read. The true line can be calculated on S from S_1 as follows :—

Example.--Instr. at S ; staff reading of $S = 4\cdot36$.
Ditto do. $S_1 = 5\cdot41$.
Difference of elevation in S&$S_1 = 1\cdot05$.
Instr. at S_1 staff reading on $S_1 = 4\cdot89$.
Ditto do. $S_1 = 3\cdot56$.
Difference of elevation in S&$S_1 = 1\cdot33$.

Then $\frac{1\cdot05 + 1\cdot33}{2} = \frac{2\cdot38}{2} = 1\cdot19$ true difference in elevation and as it is obvious that the peg at S is higher than the peg at S_1 and as the instrument is fixed at station S with the line of sight at S_1 of the centre of the object glass reading 4·89, then the true line of sight at S_1 on S will be the reading $4\cdot89 - 1\cdot19 = 3\cdot70$ instead of 3·56.

With the diaphragm screws DD (fig. 40) move the horizontal wire to read 3·70 on S and the instrument will be correctly adjusted, or raise or lower one end of the telescope by the pair of screws LL just under the telescope to the computed new reading. This will throw the bubble out; now adjust the bubble by bringing it back into the centre by its own capstan head screws, the footscrews remaining untouched.

79. The two methods just given suggests a combination of both which may be preferred by some surveyors. On setting up the level midway between two pegs and having rid the bubble of any error by the first adjustment (vide para. 77(1)) the staff is read say on peg A with a value 5·68 and it is also read on peg B with a value of 6·68 that is, the difference is 1·00 or B is one foot lower than A. The instrument is now taken to A and set up near the peg so that the staff held on the peg will just miss the eye piece of the telescope which again should rest over one foot-screw. The instrument is levelled and bubble corrected (adjustment 2) etc., and the staff is read at A by looking through the object glass of the telescope. Let us suppose the reading is 4·86 that is that the height of the line of sight is 4·86′ above A and since B is 1·00′ lower than A then the line of sight to be correct or horizontal must strike the staff held on the peg at B at 5·86′; if not, correct accordingly by diaphragm screws or collimating screws. It appears to the author that of all the methods of adjusting the level by the peg method this is perhaps the quickest and best understood and it is least liable to error as the focus does not require altering) see para. 152(5). The adjustment in fact could be tested every morning at the first set up by obtaining the difference of height of the first two pegs and then an extra two minutes work by setting close up to the second peg. The adjustments by the peg method might be considered *indirect methods.*

80. **Comparison between the Wye and Dumpy Levels.**—The Wye level is from an optician's point of view more perfect than the Dumpy form as the line of sight must pass through the centre of the lenses or the axis of the telescope and the line of sight are one and the same thing but this assumes that both the Wye supports have been ground not only circular but of exactly the same diameter and that the telescope again bears evenly in the supports. This might be true when the instrument is new but may not be so after long use.

The Wye level can be adjusted by both the direct method (adjustment vide para. 75) and the peg adjustment method and Wye levels have been known to be adjusted by the direct method and yet fail under the peg or level line in the air method (indirect method) in which case under these conditions, the latter adjustment should be resorted to, and accepted and

the instrument, worked under these conditions, will give excellent results. The Wye level is made up of a good many loose parts and is therefore a more delicate instrument to handle than the modern Dumpy, which is compact and is therefore less liable to get out of adjustment and though it cannot be tested for adjustment by the direct method it is easily adjusted when such adjustment is required by the method recommended in para. 79.

81. **Cushing's Reversible Level.**—The peculiarity of this instrument is that the object-glass-piece and eye-piece are interchangeable, each being secured to the end of the telescope tube by a slot and pin arrangement only. The express object of this arrangement, as stated in paper No. 1659, Vol. LIX., of the proceedings of the institute of Civil Engineers, is to enable Gravatt's Method of Adjustment to be applied with facility; in other words, to enable the line of collimation to be brought to coincide with the virtual line of sight, which, as has been pointed out in the Appendix, is unnecessary.

The three adjustments are thus described in the paper above referred to:—

1st. *The Vertical Collimation.*—Set up the instrument on its stand, either in or out of doors, with one foot screw under the telescope and without reference to the level of the instrument. Take out the small fixing screw at the top of the object glass cell, and, having focussed the cross lines, direct the telescope on any convenient object; and bisect it with the horizontal line, ascertaining at the same time that there is no parallax in the telescope. Now carefully turn the eye-end in its socket from right to left, until the holes in the flange of the eye-end are opposite the heads of the screws in the socket, and remove it; then replace it again, but in an inverted position, taking care to turn the eye-end from left to right until it comes to a stop, when the lines will be in their proper position. If the point be still bisected, the collimation is perfect; but if not, correct half the distance of its deviation from the horizontal line by the foot-screw under the telescope, and the other half by the two screws that give vertical motion to the diaphragm carrying the disc with the cross lines. Repeat till perfect.

2nd. *To make the line of collimation perpendicular to the vertical axis.*—The object being now bisected, and all parallax eliminated, remove the eye-end and the object glass cell from their respective sockets, and place them in the opposite ends of the telescope. If the object is still bisected, on turning the telescope half round the line of collimation is perpendicular to the vertical axis; but if not, correct half the error by the two large clamping nuts at one end of the horizontal limb, and the other half by the foot-screw under the telescope. As soon as it is found that the eye and object-ends can be reversed without any apparent change of position in the object intersected, the small fixing screw should be returned and the object cell made secure. It is important, in changing the object glass from end to end, to keep that part of the cell which has the small screw hole in it always uppermost.

3rd. *To set the bubble tube parallel to the line of collimation.*—Level the instrument stand approximately by the legs, and turn the telescope so that it is parallel to two foot-screws, bringing the bubble by their motion to the centre of its run. If it remain so, on turning the telescope half round, the level is correct; but if not, bring the bubble half

way back by the foot-screws over which it stands, and the other half by the two opposing nuts at the eye-end of the bubble-tube. Having perfected this, the levelling must be completed by turning the telescope a quarter round, so that one end of the level is over the third foot-screw, by which the bubble must be brought to the centre of its run. The bubble should now remain in the centre during a complete revolution, and the small cross-level can then be adjusted."

It is claimed for this arrangement that "the facility of adjustment of the Y level is preserved," together with the "greater stability of adjustment of the Dumpy."

82. To summarise, levels may be said to contain three important lines (*a*) the axis of the instrument, (*b*) the axis of the bubble, (*c*) the line of collimation. Adjustment 1 (para. 76) which is a temporary adjustment and which has to be made at every set up of the instrument sets the axis of the instrument vertical if adjustment 2 is subsequently made. When adjustment 2 has been made then the axis of the bubble is correct and is at right angles to the axis of the instrument which is thus truly vertical and the footscrews *cannot* be used for any further adjustment of the collimation line and this is important to remember. We are thus left with the line of collimation, which to be horizontal must be made at right angles to the axis of the instrument and this is done:— (*i*) by raising or lowering the diaphragm only (compare adjustment of theodolite for vertical collimation by diaphragm para. 66) or (*ii*) by raising or lowering the telescope to which the bubble is attached by means of the collimating screws and then correcting bubble by bubble screws only (compare adjustment of theodolite for vertical collimation by antagonistic screws, para. 66).

83. **Description of the Zeiss (Prism) Level** *see fig.* 42.—V is a screw to fix level to stockhead pin; B, slow motion screw with clamp screw on opposite side; A, micrometre screw which elevates or depresses the telescope and level; R, clamp for prism box E; X, adjusting screw for prism box E; F, prism, P, vertical axis; N, circular bubble for preliminary levelling by legs and footscrews.

(*a*) There is a reflector under the bubble. The object glass of the telescope and so called diaphragm are fixed, the focussing being done by an internal focussing slide and lens on the Porro system.

(*b*) The bubble is not graduated but its ends are reflected into the prism F.

To take a reading set up the instrument and level by bubble N and set the mirror under the reversible bubble to brightly illuminate the prism F as seen from the eyepiece. Focus eyepiece which is fitted with a scale of diopters. Sight and focus staff and by means of the screw A make a coincidence of the ends of the bubble in the prism F and take the reading.

84. **How to adjust the level.**—The telescope can be read in four positions.

I.—Eyepiece in ordinary position that is in the end with the scale of diopters and the bubble tube on the left (see plate). This is the normal position of instrument in use.

II.—Eyepiece (as above in I) and bubble tube on right.

III.—Eyepiece in objective cap and bubble tube on right.

IV.—Eyepiece in objective cap (as above in III) and bubble tube on left.

When changing over into position III the prism F should be turned round. When the eyepiece is in the objective cap (positions III and IV) focus the cross lines by sliding the objective cap in or out and while doing so place the right hand to the cap and hold the telescope in the left hand. Ordinary levelling operations are generally carried out in position I only, in special cases requiring great accuracy it is advisable to take readings in both positions I and II. Positions III and IV are exclusively intended for verifying the adjustment of the instrument. A complete adjustment can be obtained from a single station point. The adjustment is made in the following manner.

Using a levelling staff at a distance of about 150 feet readings are taken in positions I, II, III and IV, the bubble in each case being brought to the centre of its run by viewing it in the prism F whilst operating the micrometre screw A. The mean of the four readings so obtained gives a horizontal collimation which is entirely free from systematic errors.

Now by means of the micrometre screw A and with the telescope in position I set the cross wires to the computed mean of the staff readings. If the bubble is no longer in the centre of its run as seen in the upper prism F, release the clamp R and displace the prism box E by means of the milled head screw X until two halves as seen through the prism F appear to coincide. If levelling is to be done both in positions I and II then it will not be sufficient to adjust position I to the mean of the four readings but the mean reading of positions I and II must be adjusted to the mean of the four readings in positions I, II, III and IV. The above adjustments are a matter of a few minutes from one station only and the makers suggest that the instrument should be tested for adjustment daily to realise how well the instrument keeps in adjustment and also so that the worker may familiarise himself with its qualities.

85. The following points may be noted. The instrument is light and can be carried by the leveller as the total weight with stand is under 9 lbs. The telescope is fitted with stadia and owing to its internal focussing

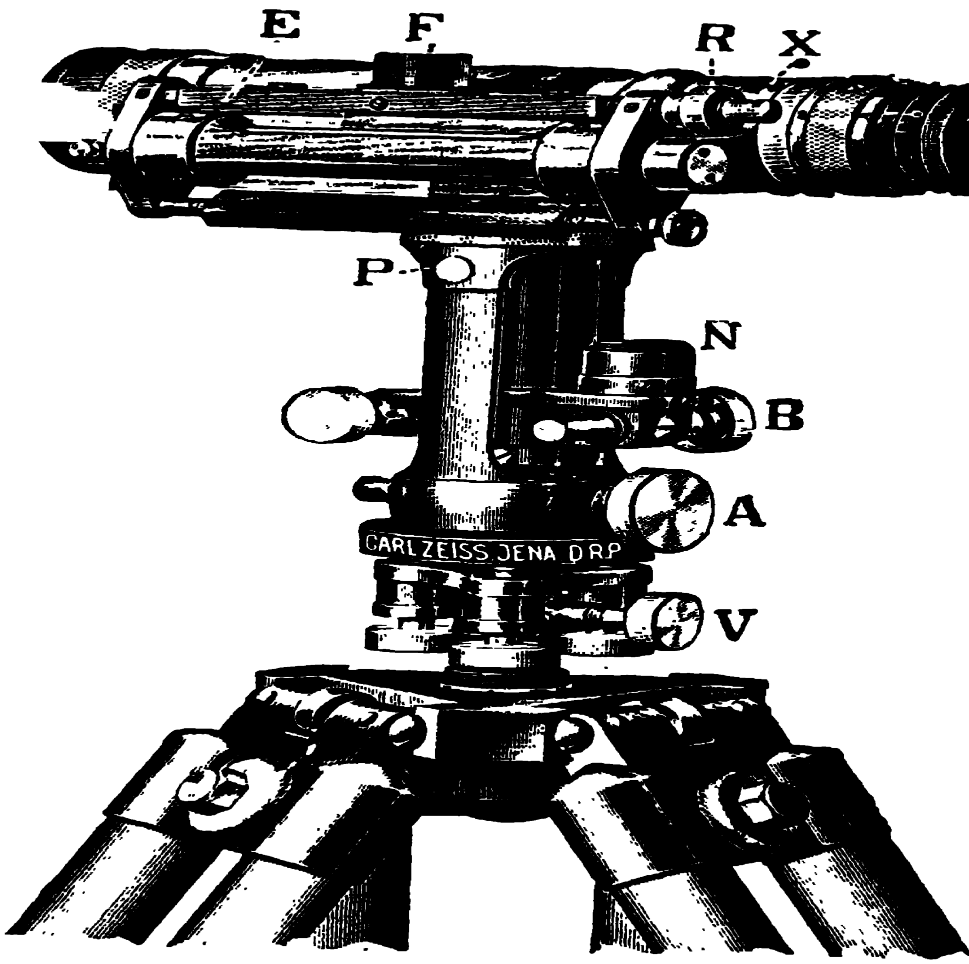


Fig. 42.

movement no constant is necessary. The lenses are said to be so good that any slight error in focussing will not alter or vitiate the readings. There is no diaphragm and the lines are engraved on the object lenses.

The position of the prism permits of the leveller keeping in one position and the reading is taken almost at the instant that the bubble takes up its adjusted position.

A precision instrument with a micrometre movement to read to $\frac{1}{10000}$ is now being made very much after the pattern and design of the above instrument.

86. CHOICE OF AN INSTRUMENT.—When choosing an instrument the following points should be decided—the focal length usually 14″ or 15″ for good ordinary work and the value of one division of the bubble of about fifteen seconds. The question of a three or four footscrew arrangement is left to the surveyor or engineer and he would perhaps be best advised to select the form he is used to. Manufacturers say that the 4 footscrew arrangement strains the axis and the 3 footscrew arrangement does not, so if there is no preference as to style of usage the manufacturers' opinion should be taken into consideration as they should know best.* The instrument should be fitted with stadia wires engraved on glass and a prismatic compass.† For all preliminary work a compass and stadia are essential. In longitudinal and cross section work the chain if used would be confined to inter staff distances and all intermediates and side shots could be put in by compass direction and stadia reading on extra staves used for this purpose. The work would be very rapid and the plot made in this way would be comprehensive and would give an extended idea of the nature of the rise and fall, slope, etc., and thus would be an excellent guide for the final alignment made with a theodolite and traverse.

The bubble should, if possible, be placed beneath the telescope rather than on the top of it as it is less liable to be injured, is more or less shaded from the direct rays of the sun, and is protected from the influence of hot hands. There should be a clamp and slow motion screw to the instrument and the object end focussing screw should be to the right of the telescope and not on the top of it. The eye focussing piece should have a double thread. The instrument should screw on to the stand or tripod as it can then be used on a parapet or wall by the different arrangement necessary for the footscrews. (See Figs. 36 and 40). Again these footscrews, working in special slots and not in slots of the tripod, when they wear loose

*In the author's opinion there is nothing to recommend the 4 screw type and he would advise the use of the 3 footscrew type only.

†An instrument fitted thus costs very little more and is most useful on location work.

can be tightened by means of small tension screws. Footscrews should be dust-capped for India and most of the Colonies. The box should be of the best seasoned mahogany with 3 hinges and it should be fitted with an extra bubble, stadia glass and the other usual accessories. A cross bubble for the instrument is not necessary. Last of all the feet of the tripod should be properly shod with a small projecting piece or stirrup to press home the leg with the foot as the pressure becomes thus a direct thrust in the direction of the grain of the wood.

The above instrument can be bought from English firms for a matter of £14 and will be found to answer almost every purpose of the engineer.

87. **The levelling staff.**—Their number is legion, each with its own peculiarities of graduation but excepting this there are only two kinds, one, the target rod of America and the other, the self-reading rod or staff, as it is usually called. The Americans, for many years, claimed an advantage for the target rod but have recently, owing to improvements made in precision instruments, changed their views so that many of their foremost engineers prefer the self-reading staff. With the self-reading staff errors are compensating, work is accelerated, the surveyor alone is responsible for his mistakes or errors and its accuracy is acknowledged by the fact that most of the world's precise levelling is accomplished on the self-reading type. Level rods or staves are from 10 to 15 feet in length. The 10 and 12 "foot" staves are usually in one piece about 1¼ inches in thickness and 2½ inches face, the face being countersunk for the graduation. The 15 'foot' rod like the Sopwith is collapsible. This collapsible style of rod has many disadvantages. It is heavy, swells with rain so that it is sometimes difficult to close or extend, and the staff man may ruin a whole day's work by not fully extending it to the spring catches, and this may remain unnoticed and certainly will, if the joint is not more or less in the field of view of the telescope. The springs also become weak and a slight jar allows one of the slides to drop. The disadvantages seem therefore to outweigh any advantages in length and portability. The Indian or Roorkee pattern staff is a simple straightforward staff and for this reason is largely used. The figures denoting full feet are in red and might with advantage be larger. However the best staff for the individual is the one he is used to. The G. T., Sopwith and the revised Roorkee pattern staves are illustrated in plate X. In the Roorkee pattern the upper edges of the bars or graduations are even numbers. 3·00 is the *top* of the red bar opposite the red figure 3.

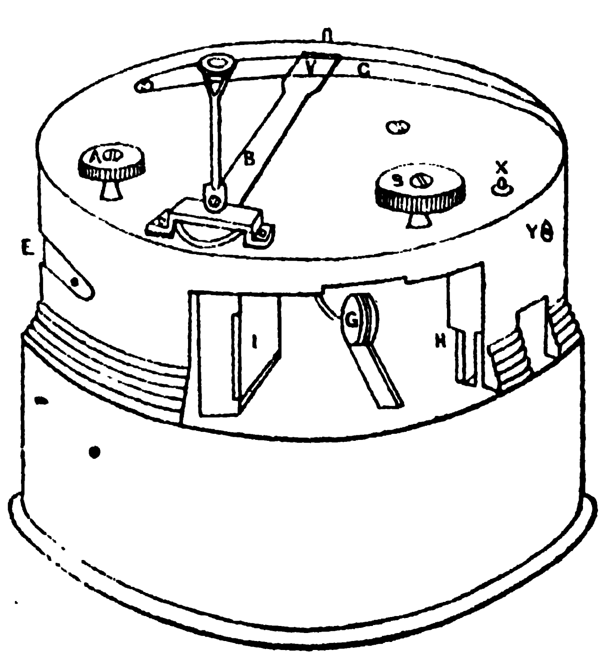
88. **The Pocket Sextant.**—The pocket sextant is one of a numerous class of reflecting instruments, and possesses the advantages of

being portable, of requiring no other support than the hand, and of only requiring one easy adjustment. This instrument is more correct than the compass, as by means of the vernier, angles can be read to within one minute on the graduated arc; and being a reflecting instrument, it is not influenced by local attraction or magnetic variation. It can also be used on horseback and in all weathers. When not required for use, the sextant is packed in a small box, in which manner it can be conveniently carried either in the pocket, or in a small leather case slung over the shoulder. When required for use, the case should be unscrewed and the small slide at the under part of the sextant pushed back; the dark glasses can then be pressed down through the opening, by means of a pair of levers at the side of the instrument. The lid should then be reversed and screwed on to the lower part of the sextant, which will then appear as shown in the sketch, (*Fig.* 43), the telescope having been withdrawn if it had been previously placed within the instrument.

The various parts of the sextant are named as follows:—I, the index-mirror; H, the horizon-glass, the upper half of which is silvered and therefore reflects objects; B, the index-arm; S, a screw, by means of which the index-arm is moved; V, the vernier, which enables minutes to be read; A, the adjusting-key, X and Y, the key-holes for adjusting the horizontal-glass; a screw for holding the support of the telescope is sometimes added near the adjusting-key; E, the eye-hole; G, the glasses for intercepting the sun's rays; C, the graduated arc.

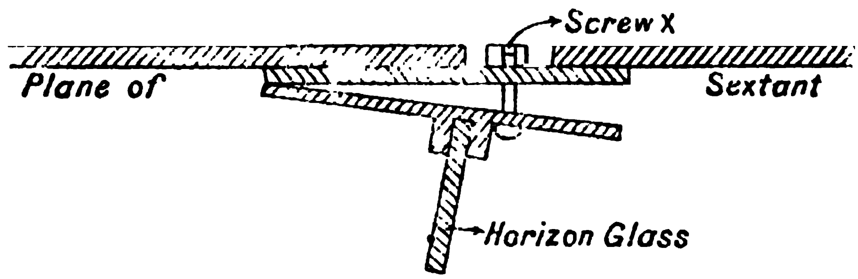
Before taking an angle with the sextant, the instrument should be examined to see whether it is in adjustment.

Fig. 43.



89. **Adjustment.**—In the box sextant and in the ordinary nautical sextant, the index glass is permanently fixed by the maker at right angles to the plane of the sextant. Provision is made only for adjusting the horizon glass, which ought to be parallel to the index glass when the latter's index reads zero while the planes of both glasses should be at right angles to the sextant plane. The key, which, when not in use, is kept secured to the box, is inserted in one or other of the holes X and Y in order to effect these adjustments. The upper screw X, tilts the horizon glass as shewn in the sketch above, and helps to place it at right angles to the sextant plane, which is taken as parallel to the under surface of the cover plate. The screw Y on the side of the box moves the glass laterally and effects parallelism of the index glass.

Fig. 44.



There are therefore two distinct adjustments which are, however, performed together when the index error is very small; viz:—

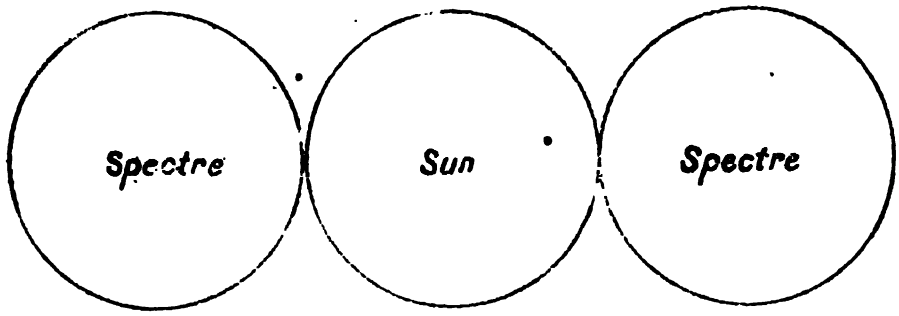
(1) to place the horizon glass perpendicular to the sextant plane.

(2) to make the plane of the horizon glass parallel to the plane of the index glass when the index arm of the latter is at zero. This adjustment is referred to as the adjustment for the index-error (when it is small).

When the index error is fairly appreciable it has to be used as a correction to all observed angles. Set the zero of the vernier coinciding with the zero of the arc or limb, and then sight some distant object through the transparent part of the horizon glass, the said object being distant from the observer not less than half a mile. [The telescope should be used if the sextant has one.] The reflected image or "spectre," of the object should now also be visible, and if the instrument is in adjustment, the two images should coincide exactly. If they do not, first bring them to the same horizontal level by means of screw X and then in exact coincidence by means of screw Y. It will generally be found that only a slight turn of Y is sufficient to effect the required coincidence; and if the index error is very small no further adjustment is necessary.

But when the index error is great, and preferably in all cases but the most insignificant, it is necessary to detect its amount and to apply it as a correction to all angles read from the instrument. For this purpose the sun should be observed, care being taken to use the dark slides or shades both for direct and reflected vision.

Fig. 45.



The sun should be sighted through the transparent portion of the horizon glass, and if all is right, a clear outline of his limb should be obtained. This would be the case if the direct and spectral images coincided; a distorted sun would be the appearance if coincidence were not perfect. The distortion is removed by means of the screws X and Y as described in the adjustment above, but it is done more easily by first holding the sextant vertically and using screw X, and then horizontally using the screw Y.

The index arm is detected and allowed for thus. Hold the sextant, say horizontally, and bring first the left limb of the "spectral" sun to touch the right limb of the direct sun as shown in the above sketch. In one case the reading will be on the arc of excess (if the index error is not half a degree) and in the other on the regular arc or limb. If these readings agree (and in that case they should each show the diameter of the sun or 32′ 16″ as nearly as possible), there is no index error; otherwise the *correction for index* is half the difference of the readings.

It is advisable to take two or three pairs of readings and record their mean. Thus

	Reading on limbs.	Reading on arc of excess.
1st set	35¼′	29½′
2nd set	34½′	29′
3rd set	35¾′	29½′
Total ..	105½	88
	−88	
	17½	

$$\therefore \text{ Index error} = \frac{35}{12} = 3' \text{ (nearly.)}$$

The limb is negative and the arc of excess positive. Therefore if the reading on the limb exceeds that on the arc of excess, the correction is subtractive, if vice versa, additive.

N.B—When the index error is nearly 30′ or $\frac{1}{2}^{\circ}$ both readings may be on the arc of excess or on the limbs: if so, half their sum (i.e. their mean) is the correction——subtractive if on the limbs, and additive if on the arc of excess.

The index error is noted, and all angles read with the sextant, i.e. all readings, are corrected accordingly, subtracting for the limb and adding for the arc of excess.

Parallax, when the objects observed are very close, the parallax of the instrument exerts an influence on such small angles. To allow for it, it is only necessary to ascertain its amount, which is done by placing the index at zero, and looking through the instrument at any horizontal object such as the top of a wall, when, if influenced by parallax, it will appear as a broken line; but by moving the index a little way on the arc of excess or to the left of the zero, the broken line will re-unite and the small angle which the instrument then shows will be the amount to be allowed for parallax.

90. **To take an angle.**—The observer looks either through the telescope or hole in the middle (having previously raised the levers of the dark glasses) at the left hand object, holding the sextant horizontal in his left hand; with his right he turns the milled head screw S, until the other object reflected from the index glass, appears upon the silvered part of the horizon glass, exactly covering or agreeing with the left-hand object seen direct through the unsilvered portion of the horizon glass; the angle is then obtained by the vernier to one minute.

If the required angle be a vertical one, the sextant is held in a vertical position by the right hand, while the left turns the milled head S until the object is brought down to the horizon.

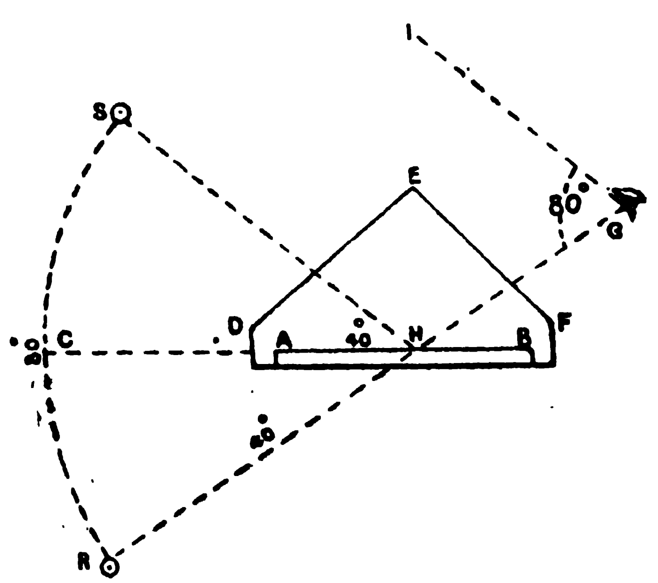
Artificial horizon.—When the altitude of a celestial body is taken at sea, it is brought down, as the term is, to the natural horizon, and the measure of the angle or height of the object is read off upon the graduated arc; but on land, the natural horizon can seldom be used, on account of its irregularity; recourse is then had to what is called an *artificial horizon*,

such as a vessel containing water, mercury, or other fluid. The observer places himself in a situation to see the reflected image of the sun, or other body, in the fluid: he has only then to bring down the image, as reflected from the index glass, until it reaches its reflection in the fluid: the altitude will then be *half* the number of degrees, indicated by the graduated arc, subject to certain corrections, not necessary to be explained here.

The reason of only taking half the number of degrees will be seen from the following explanation:—

Let AHB represent the surface of the quicksilver contained in a wooden trough, whose plane is continued to O; DEF, the roof, in which are fixed two plates of glass, DE and EF., whose surfaces are plane and at an angle to each other, and ☉ the sun at S, whose altitude is required. Now the ray SH, proceeding from the sun's lower limb to the surface of the quicksilver, will be reflected thence to the eye in the direction of HG, and the lower limb of the sun's image, reflected from the quicksilver, will appear in the line GH, continued to R; and it is a well known principle in optics, that the angle of incidence, SHA or SHO, is equal to the angle of reflection GHB; and as the angle AHR, or OHR, is the opposite angle of GHB, it is therefore equal to it, and to the angle SHO, the altitude of sun's lower limb above the horizontal plane; so that, supposing the angle SHR, measured by a sextant, to be 80°, the altitude of the sun's lower limb will then be 40°, subject to the corrections as above.

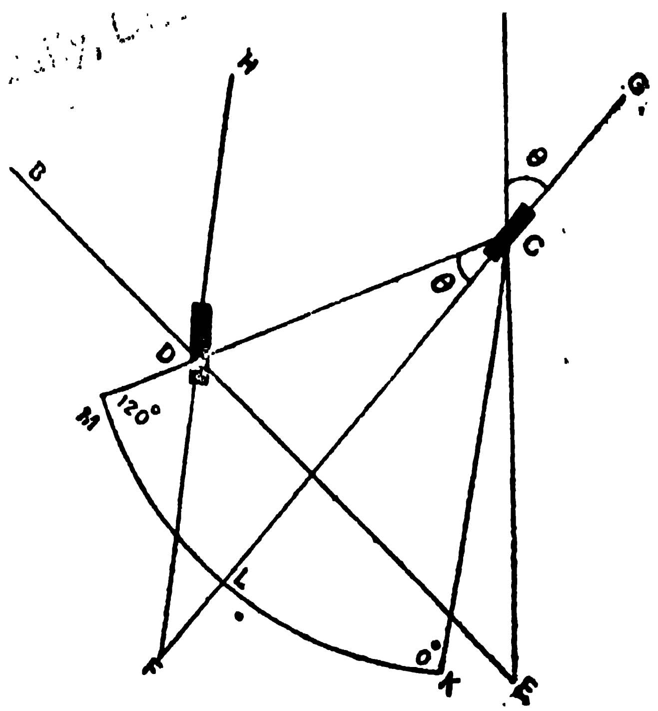
Fig. 46



92. **Nautical sextant.**—See fig. 47 consists of a brass frame work made in the form of a sector of a little more than 60 ° and it is graduated along the circular rim. To the centre of the arc is attached an arm L with vernier, clamp and show motion screw. This arm carries the *index glass* (mirror) C at the centre. There is a half silvered mirror at D called the *horizon glass* which makes an angle about 60° with MC. There is a telescope through which an object is seen through the unsilvered portion at D, and the image on the silvered portion on D reflected by the mirror at C. The object glass of the telescope is so near the mirror at D that the mirror is out of focus hence you see the reflected image superimposed as a " spectre." Four dark glasses are fixed between the index glass and horizon glass and any one of these can be used to cut off or moderate the intensity of light

from the reflected object if very bright, and there are four dark glasses, which can be turned down behind D to cut off light from an object viewed directly. The telescope fits in to a ring which is known as the "up and down" piece by which the telescope can be raised or lowered till the objects seen directly and by reflection appear of the same brightness.

Fig. 48.



The principle of construction of the sextant may be gathered from the following demonstration.

In a given plane let A and B be two objects and E the eye. It is required to measure the angle AEB (see fig. 48).

Let C be the index glass and D the horizon glass, D is fixed in position with its plane perpendicular to the given plane. The centres of the mirrors C and D are relatively fixed. B is sighted through the transparent portion of the glass D, so that a ray of light BDE reaches the eye, E, *directly* ; and at the same time C is rotated until the reflected image of A, or its "spectre" coincides with the image of B, i.e., the ray AC is reflected along CD and is again reflected along DE.

Produce the planes of the index glass mirror in both directions to F and G and the horizon glass mirror to F and H. The planes meet in F. Then by the laws of optics

$$\text{Angle } ACG = \text{Angle } DCF = \theta \text{ say};$$
$$\text{Angle } CDH = \text{Angle } EDF = \phi \text{ say}.$$

Then angle ECF $=$ angle ACG $= \theta$ so that angle DCE $= 2\theta$

also angle CDE $= 180° - 2\phi$.

$\therefore$ angle AEB $= 180° - (2\theta + 180° - 2\phi) = 2(\phi - \theta)$

and angle CFD $=$ angle CDH $-$ angle DCF $= \phi - \theta$

$\therefore$ angle AEB $=$ twice angle CFD.

Fig. 47.

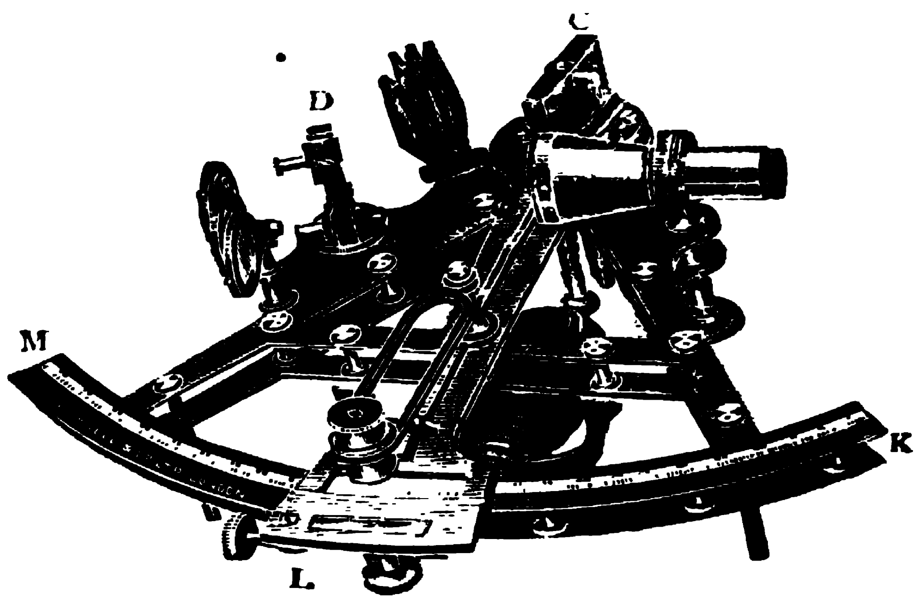
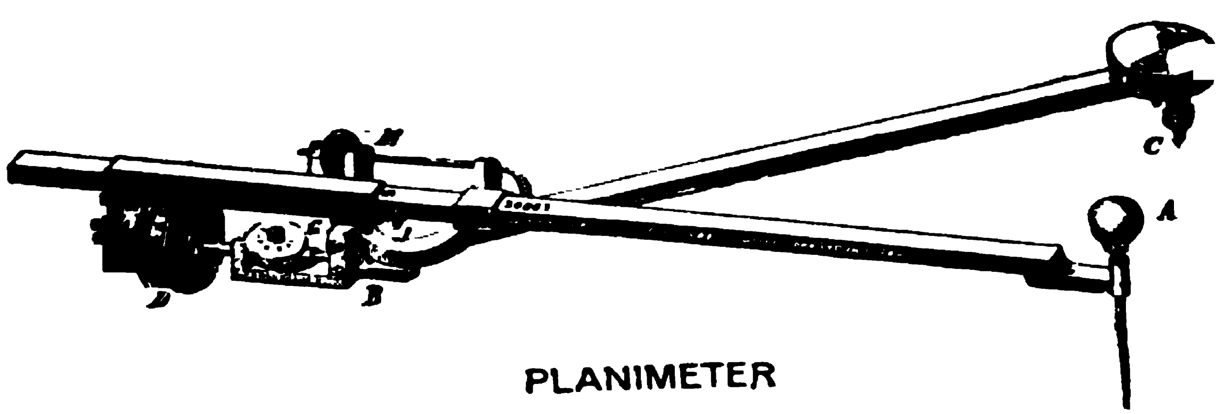


Fig. 49.



PLANIMETER

Draw CK parallel to DF and of convenient length. With centre C and radius CK describe an arc, cutting CF and CD in L and M respectively.

Then angle A E B = twice angle LCK = twice arc L K.

C L rotates with the plane of the mirror C and when it coincides with C K the angle L C K = 0° and ∴ angle C F D = 0°. If therefore, the arc K L M be graduated, with zero at K (i.e. when the mirrors are parallel) to read double the angle (L C K) indicated by an index arm attached to the mirror, in production of its plane and rotating with it, an instrument to measure angles such as A E B is provided. In the sextant the angle M C K or angle D C K is always 60°, so that the arm K M is graduated to *read* 120°. If the angle A E B is greater than 120° it is measured in two portions, an intermediate object being observed to.

93. **Adjustments.**—(1) If the reflected image does not pass exactly over the direct image then the reflectors are not perpendicular to the plane of the sextant and as the index glass is fixed by the maker, only the horizon glass can be adjusted, and this is done by means of the small screw at the foot of the horizon glass which tilts the glass or if there is no screw for this purpose the mirror must be corrected by wedges of paper being placed under the frame.

(2) If the line of sight of the telescope is not parallel to the plane of the arc then a correction is made by means of the up and down piece and this correction or adjustment is independent of the other adjustments.

Place the sextant on its three legs on a table and through the telescope observe at a spot on a wall 20 or 25 feet away and mark the spot. Now place two pieces of wood of the same height as two small match-boxes and of the height of the centre of the telescope one at each end of the arc and on top of it and observe over the tops of the slips of wood to the mark with the eye. If the mark is within a half of an inch of the line of sight over the tops of the pieces of wood there is no need to correct as a difference of half an inch at 20 feet will make an error of only about one second in the angle, but when the error is large the telescope must be inclined or declined as the case may be by means of the collar and up and down piece.

(3) To determine the index error. This is best done by observing to the sun and this has been given in paragraph 89 (2), but it is necessary to note that half the difference of the readings will be the index error and half the sum of these readings will be the correct diameter.

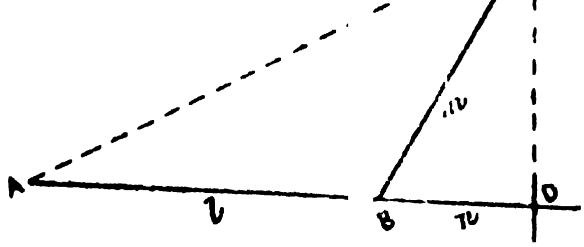
In example given this works out to 32′ 15″ as the diameter and 3′ (nearly) as the index correction over 6 readings. The readings on the arc of excess being less than those on the arc of the instrument the index error of 3′ is to be *subtracted* from all the readings of the instrument.

The sextant therefore can be said to be an instrument specially suited for observations at sea with a natural horizon. The angle subtended between two objects is the angle in the plane of the two objects, which angle would have to be reduced to the horizontal plane ; in this respect it is therefore inferior to the theodolite (see para. 66).

94. **The planimetre** is a mechanical integrator and is used to find out the area of any irregular figure. The best known is that of Amsler (Fig. 49). It consists of two arms, one the tracing arm A to which the recording wheel D with dial G and tracing point is attached and the other the main arm C which is pivotted to the tracing arm and is also pivotted to the paper by means of the needle-point pressed into the table on which the instrument rests.

When the instrument is placed on the paper ready for use there are three points of contact, one the tracing point, two the rim of the recording wheel and three the needle point. To the central pivot B is attached a sleeve into which the tracing arm slides which enables the instrument with reference to the length of the tracing arm to be set to some particular index and the distance between the tracing point and this pivot multiplied by the circumference of the recording wheel is equal to the area circumscribed in units to which the bar is set when the needle-point is fixed *without* the area to be circumscribed.

Fig. 50.



The recording wheel D. in fig. 49 is divided into 100s of its circumference and a vernier gives the 1000ths. By means of a wormed wheel a dial indicates the number of revolutions made by the wheel. If for instance the instrument was set to 0 and the tracing point A was taken along the periphery of a figure you might obtain the following reading 1·967 and this would be obtained as follows :—1 on the dial, 96 on the recording wheel and 7 on the vernier and the area of the figure would be l × 1·967 (l = distance A B in terms of the unit to which the bar is set).

Again when the pivot C is within the figure to be circumscribed by the tracer A. (Fig. 50) it will be seen that in certain positions the wheel will not register and this is when the angle ADC. is a right angle so that besides the area as given by the recording wheel, an area equal to a circle of which AC is radius, has to be added. This circle is called the zero circle of the instrument and $AC^2=AD^2+CD^2$

$$BC^2=BD^2+DC^2$$

$$\therefore AC^2=AB^2+BC^2-BD^2$$

$$\text{or} \quad AC^2=AB^2+BD^2+2AB.BD+BC^2-BD^2$$

$$=l^2+m^2+2ln = \text{radius}^2.$$

$\therefore$ area of zero circle $=(l^2+m^2+2ln)\,\pi$

The area of the zero circle is computed by the makers for each instrument and is engraved on the top of the bar over each index or setting and nearest to the setting for which it is intended.

(*a*) *To take out an area when the pivot C is without the area.* First roughly run the tracer A. along the periphery to make sure every point on it is reached without the instrument being awkwardly placed and then press in the needle point C and add the small weight at C to steady it. Start from any point on the periphery and record the reading, let it 2·676. Move the tracer carefully along the periphery in a *clockwise* direction and return to the starting point and let the reading be 4·593. The difference of reading multiplied by the length of the bar l will equal the area. If the bar had been set at index 10 sq. inches then the area in example would be (4·593—2·676) 10=19·17 sq. inches.

If the motion of the tracing arm is *clockwise* then the first reading or lesser reading is always subtracted from the second or greater reading to get the difference and it is convenient to remember this. The dial must be watched to see when a 0 is passed in which case the second reading is in 10s. Example :—instrument is turned in a clockwise direction first or starting reading is 8·930 and closing reading is 0·960. It is evident for any area to be enclosed 0·960 clearly means 10·960 but it might also mean 20·960 that is that the dial registered two 0s and so forth. Again if the dial passes over one 0 and then has a retrograde motion coming back and repassing a 0 then these cancel.

(*b*) When the area to be circumscribed is large such that the pivot C is placed *within* then the same procedure is adopted as before but the area of the zero circle or the constant to which the bar is set, is added to the

difference of readings. If this constant or area of zero circle had been 22,196 engraved on the bar just above and next to the index line for 10 sq. inches then in the example given above since this area must be added we get $(22{\cdot}196+4{\cdot}593-2{\cdot}676)\ 10=241{\cdot}13$ sq. inches, that is, an area of 19·17 sq. inches over and above the area of the zero circle of 221·96 sq. inches$=$241·13 sq. inches.

(*c*) It will be noticed that the sleeve into which the tracing arm slides is fitted with a clamp and slow motion screw M and their uses are not only to get the index lines to coincide so much as to adjust the instrument to give true values for areas of drawings and surveys on paper which have contracted or expanded under exposure. Every survey when it is plotted or projected should have ruled squares or graticules of certain dimensions. These squares or graticules become warped perhaps (see paragraph 7*a*) but according to the original plotting to scale they must contain a certain area. Let us consider a survey and take a square 8 inches by 8 inches equalling an area of 64 sq. inches. If the plainmetre is set to index 10 and the pivot point C is without the area the difference of reading should be 6·400; but if the paper has contracted the instrument might give 6·390. Since the area is 64 sq. inches the instrument must be made to read 6·400 and the rule is to *lessen* area *lengthen* bar or *vice versa* and in this case the bar would be shortened. When the instrument is thus adjusted to the paper all areas for that paper will be true areas.

95. **Copying Plans, Maps, &c., by hand.**—There are several methods of doing this when the copy is to be of the same size as the original, such as placing the plan to be copied with a sheet of paper over it on a tracing glass, placed in such a position that a strong light may fall on it *from behind* or *underneath* and then tracing it off. Or by placing a sheet of thin paper, having its under side blackened (by rubbing finely powdered black lead or a soft lead pencil over it), on the sheet of paper that is to receive the copy, the original being placed over both, and the whole made steady by placing weights thereon: all the lines of the copy must now be carefully passed over with a fine tracing point, and with a pressure proportionate to the thickness of the paper: the paper beneath will receive corresponding marks forming an exact copy, which may afterwards be inked in. All these systems of copying hurt, in a more or less degree, the original drawing. Tracing cloth is now used in engineers' offices very largely. This cloth is rendered sufficiently transparent to admit of very fine detail work being traced off, and will permit color being applied. It is as well, however, to apply the color on the reverse side of the cloth, as it is

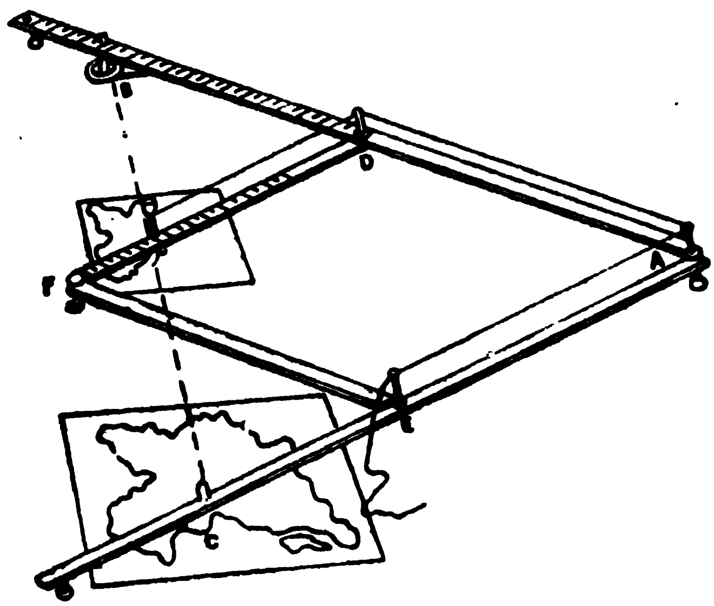
difficult to get it to lay evenly on the cloth. Such unevenness in a flat shade scarcely shows when seen through the tracing cloth. Tracing paper was formerly much used, but has now been entriely superseded by tracing cloth. In India, tracing paper soon gets dry and brittle, and will not stand handling. When the drawing is to be reduced or enlarged, the pantagraph, eidograph, the method of copying squares, or the lens must be resorted to.

96. (*a*) **The Pantagraph**, consists of four rulers, AB, AC, DF and EF, (*Fig.* 51), made of stout brass. The two longer rulers, AB and AC, are connected together at A, and have a motion round it as a centre. The two shorter rulers are connected in like manner with each other at F, and with the longer rulers at D and E, and being equal in length to the portions AD and AE of the longer rulers, form with them an accurate parallelogram, ADFE, in every position of the instrument. Several ivory castors support the instrument, parallel to the paper, and allow it to move freely over it in all directions. The arms AB and DF are graduated and marked $\frac{1}{2}$, $\frac{1}{3}$ &c., and have each a sliding index, which can be fixed at any of the divisions by a milled-headed clamping screw, seen in the engraving. The sliding indices have each of them a tube, adapted either to slide on a pin rising from a heavy circular weight, called the fulcrum B or to receive a sliding holder with a pencil or pen, or blunt tracing point, as may be required.

When the instrument is correctly set, the tracing point, pencil, and fulcrum will be in one straight line, as shown by the dotted line in the figure. The motions of the tracing point, and pencil are then each compounded of two circular motions, one about the fulcrum and the other about the joints at the ends of the rulers upon which they are respectively placed. The radii of these motions form sides about equal angles of two similar triangles, of which the straight line BC, passing through the tracing point, pencil and fulcrum, forms the third side. The distances passed over by the tracing point and pencil, in consequence of either of these motions, have then the same ratio; therefore, the distances passed over, in consequence of the combination of the two motions, have also the same ratio, which is that indicated by the setting of the instrument.

The diagram represents the pantagraph in the act of reducing a plan to a scale half the original. For this purpose the sliding indices are first clamped at the divisions upon the marks marked $\frac{1}{2}$: the tracing

Fig. 51.



point is then fixed in a socket at C, over the original drawing ; the pencil is next placed in the tube of the sliding index upon the ruler DF, over the paper to receive the copy, and the fulcrum is fixed to that at B, upon the ruler AB. The instrument being now ready for use, if the tracing point at C be passed delicately and steadily over every line of the plan, a true copy, but of one-half the scale of the original, will be marked by the pencil on the paper beneath it. The fine thread represented as passing from the pencil quite round the instrument to the tracing point at C, enables the draftsman at the tracing point to raise the pencil from the paper, whilst he passes the tracer from one part of the original to another, and thus to prevent false lines from being made on the copy. The pencil holder is surmounted by a cup, into which sand or shot may be put, to press the pencil more heavily on the paper, when found necessary.

If the object were to enlarge the drawing to double its scale, then the tracer must be placed upon the arm DF, and the pencil at C and if a copy were required of the same scale as the original, then the sliding indices still remaining at the same divisions upon DF and AB, the fulcrum must take the middle station, and the pencil and tracing point those on the exterior arms, AB and AC, of the instrument. The instrument should be tested by means of a line at C and its ½, ⅓ lengths etc., when reduced, before commencing work on a map.

(*b*) **The Ediograph,** which is represented in the accompanying engraving, (*Fig.* 52) is a far superior instrument to the pantagraph, being more exact in its work, and not so limited as regards ratio of reduction.

The point of support when the instrument is at work is a heavy weight shown at H, from the under side of which three or four projecting needle

points fix the instrument firmly to the drawing paper. Springing from this weight is a short standard or fulcrum, attached to a sliding-box, K, in which slides the centre beam, C, and to any part of which it may be clamped by means of a clamping screw.

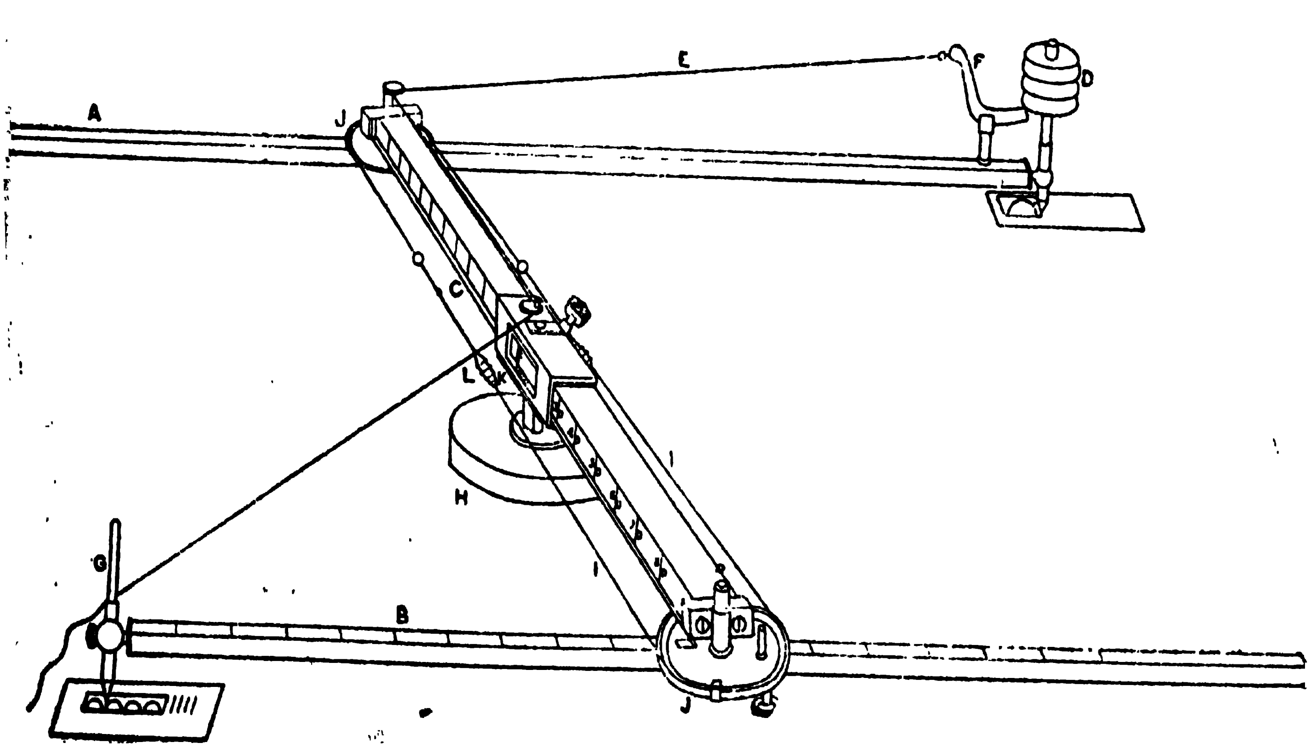
At the ends of the central beam are two pulley wheels, JJ, the centre pins of which revolve in sockets at the ends of the beam. Two steel bands, I, I, attached to the pulley wheels, give them an exactly simultaneous motion, and these bands have a screw adjustment, L, by means of which they may be tightened.

The arms A and B are made to slide through boxes under the pulley wheels, and may be clamped at any proportion of their lengths in the same manner and the central beam, C, may be made to slide and clamp in the box K.

The arm B carries a tracing point, G, and the arm A carries a pencil point, D. The pencil holder may be raised by means of a cranked lever F, attached to a cord, E, which passes over the centre beam, and thence the tracing point, G.

The two arms and the beam are divided into 200 equal parts, which are figured 100 each way from the centre, and may be read to 1000th by means of the verniers on the sliding-boxes.

Fig. 52.



There is a loose weight which may be attached when the instrument has been set, and the object of which is to steady it when there is a great difference in the proportions to which the instrument is being worked.

It will be observed that the pulley wheels give the easiest possible motion: these wheels should be of exactly equal diameter, and as they are turned in a lathe, this equality may be obtained to the greatest perfection.

To bring the instrument into adjustment let the verniers be set to zero, which will bring them to the centres of the arms and of the central beam; place the arms at right angles to the beam, as near as you may guess, and make a mark with the tracer and pencil point, and turn the instrument round so as to bring the pencil point into the mark made by the tracer; by doing this you will make the tracer move exactly to the mark previously made by the pencil, if the instrument is in adjustment; if otherwise, the error in difference should be bisected, and the adjusting screws on the band should be moved until the tracing-point comes exactly into the bisection.

97. **Copying by squares.**– To explain the method of copying by squares let the annexed engraving (*Fig.* 53), represent a plan of an estate, which it is required to copy upon a reduced scale of one-half. The copy will therefore be half the length and half the breadth, and consequently will occupy but one-fourth the space of the original.

Fig. 53.

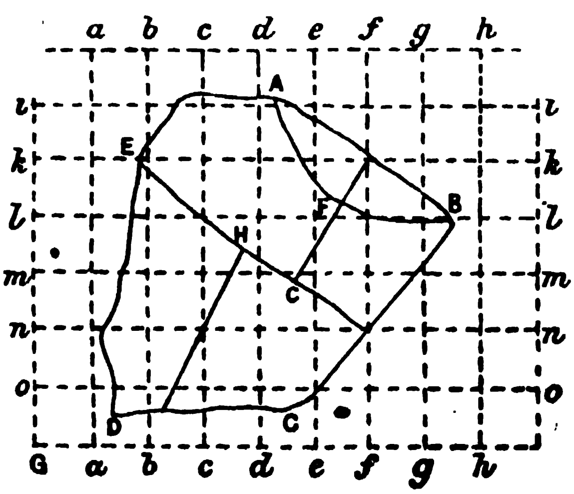
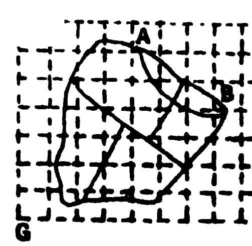


Fig. 54.



Draw the lines FI, FG at right angles to each other; from the point F towards I and G, set off any number of equal parts, as F*a*, *ab*, *bc*, &c., on the line FI, and F*i*, *ik*, *kl*, &c., on the line FG; from the points, in the line FI, draw lines parallel to the other lines FG, as *aa*, *bb*, *cc*, &c., and from the points on FG, draw lines parallel to FI, as *ii*, *kk*, *ll*, &c., which being sufficiently extended towards I and G, the whole of the original drawing will be covered with a net-work of small but equal squares. Next draw upon the paper intended for the copy, a similar set of squares, but having each side only one-half the length of the former, as is represented in *Fig.*

54. It will now be evident that if the lines AB, BC, CD, &c., *Fig.* 53, be drawn in the corresponding squares in *Fig.* 54, a correct copy of the original will be produced, and of half the original scale. Commencing then at A, observe where in the original the angle A falls, which is towards the bottom of the square marked *de*. In the corresponding squares, therefore, of the copy, and in the same proportion towards the left hand side of it, place the same point in the copy: from thence tracing where the curved line AF crosses the bottom line of that square, which crossing is about two-fifths of the width of the square from the left-hand corner towards the right, and cross it similarly in the copy. Again, as it crosses the right hand bottom corner in the second square below *de*, describe it so in the copy; find the position of the points similarly where it crosses the lines *ff* and *gg*, above the line *ll*, by comparing the distances of such crossings from the nearest corner of a square in the original, and similarly marking the required crossings on the corresponding line on the copy. Lastly, determine the place of the point B, in the third square below *gh* on the top line; and a line drawn from A in the copy, through these several points to B, will be a correct reduced copy of the original line. Proceed in like manner with every other line on the plan, and its various details, and thus will be obtained the plot or drawing, laid down to a small scale, yet bearing all the proportions in itself exactly as the original.

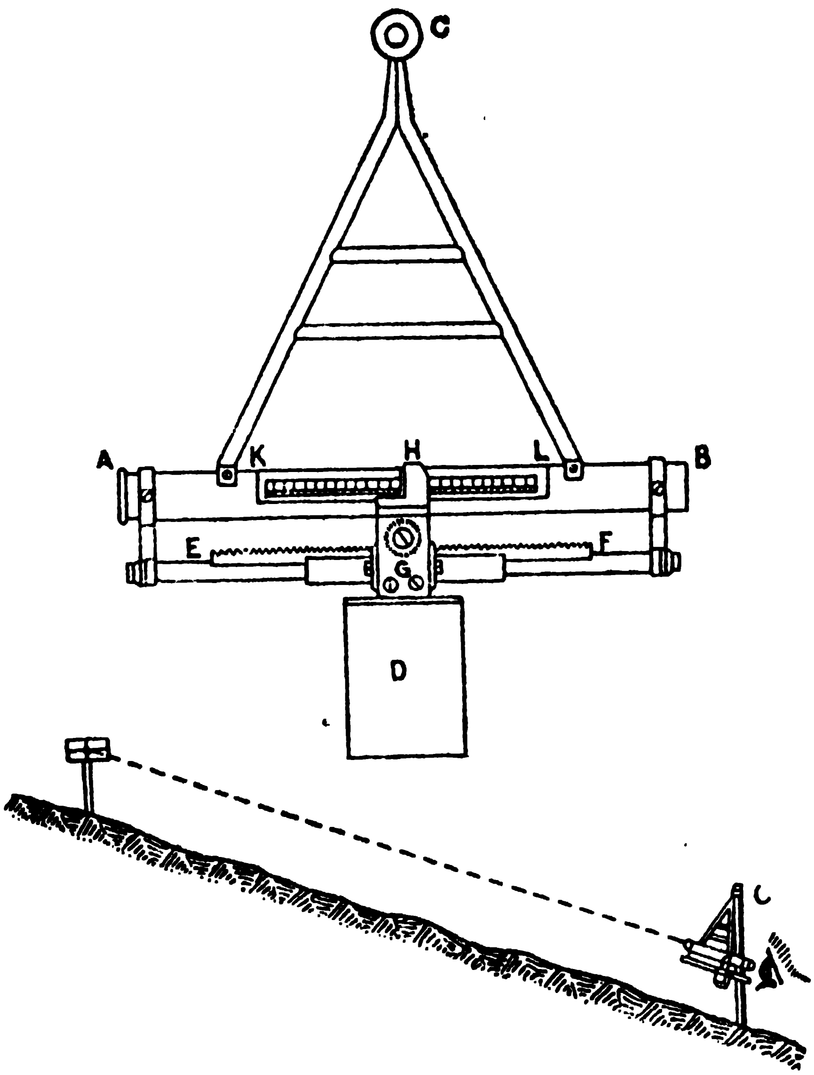
It may appear almost superfluous to remark that the process of enlarging drawings, by means of squares, is a similar operation to the above excepting that the points are to be determined on the smaller squares of the original, and transferred to the larger squares of the copy. The process of enlarging, under any circumstances, does not, however, admit of the same accuracy as reducing.

It is also as well to remember, that when a drawing is reduced to half the scale, the size is diminished to $\frac{1}{4}$th; or if the scale is $\frac{1}{3}$rd of the original, then the size will be $\frac{1}{9}$th; and *vice versa*, if the drawing is enlarged.

98. **Copying by the Lens.**—A suitable lens fitted to a camera can be used to reduce plans by replacing the ground glass with a sheet of clear glass covered by fine tracing paper. The drawing or plan to be reduced should be pinned on a vertical stand in strong sun-light, and when focussed to the required scale the lines thrown on the tracing paper can be followed with a fine pencil. The process is trying to the eyes of the operator, but is useful when only one copy of the reduction is required.

99. The Ceylon Ghat Tracer.—This is a useful instrument for carrying out rough preliminary survey of a hill route of any required gradient.

Fig. 55.



It consists of a hollow metal sighting tube AB fitted with an eye-piece at one end and cross wires at the other. The tube pivots round the point C, which is held suspended from an upright staff. The required inclination is given to the sighting-tube by means of the weight D, which is capable of motion along the rack EF by means of the screw G. H is an index which moves along a graduated scale of gradients KL marked on the body of the tube.

Thus, supposing a gradient of 1 in 43 has to be laid out along a hill slope. The weight D is moved along until HK reads 43 on the scale. A man with a sight-vane, which is set at the height of the axis of the sighting-tube above the foot of the suspending staff, is then sent along the hill-side to a convenient distance, usually from 50 to 60 yards, until the

place is found where the cross-wires intersect on the centre of the sight-vane. The foot of the vane is then resting on a point, from which the slope down to the observing point is one of 1 in 43. The assistant drives a a peg in here, to which the surveyor advances and repeats the operation. In the figure the sight-vane is shown as turned through a right angle.

100. **The Abney Clinometer or Level** consists of a sighting-tube with one horizontal wire and a piece of reflecting glass placed so that one edge is along the vertical sight line and so that on looking through, half the aperture is filled up by the mirror and half is vacant for viewing the object.

To this tube is fixed a graduated arc and vernier. The vernier is turned by a milled head screw to which is also attached a bubble. This bubble is so placed that its reflection is cast down on to the mirror. When the line of sight is level the bubble will be seen in the centre of the line of the mirror and the vernier will read 0°. A little thought will make it evident that, if the line of the sight is inclined and the milled head screw is turned till the bubble becomes level so that its reflection is seen, the vernier which is also moved by the milled head screw will give the angle of elevation or depression and in some instruments also the gradient and the value to be used in reducing a chained distance to the horizontal. This little instrument which is not more than 4 inches by 2 inches is less cumbersome than the ghat tracer, is just as accurate if not more so, and has other uses as well. No engineer should be without an Abney clinometer or level when working on preliminary alignments. To adjust the Abney level it is probable that a level or theodolite is necessary in order to obtain a level line and then on sighting with the Abney level if the vertical arc is set at 0° and the bubble is not in the centre the bubble screws are to be used to correct the bubble or an index error noted. Another method will suggest itself when the heights of two known points are given and the tangent of the angle is computed as in the next paragraph. The *De Lisle* reflecting level is also a quick and accurate method of laying down preliminary gradients for hill roads, railway etc.

101. **The Tangent Clinometer** (Survey of India pattern)—Perhaps one of the most useful instruments to the topographical surveyor using the ordinary planetable and plain sight rule is the tangent pattern clinometer. The instrument consists of a sight-vane and a peep-vane mounted perpendicularly on a bar at the end of which is a milled head screw which works against the bed-plate. The bar is pivotted at the sight-vane end, and on the bar and parallel to it is, placed a level so that the bubble is moved by means of the milled head screw which raises or depresses the bar and thus

elevates or depresses the line of sight through the peep-hole and the 0 division on the sight-vane. The height of the peep-hole is about $3\frac{1}{2}$ inches above the bar and the length of the sight-vane is about 7 inches. The sight-vane is an inch in breadth and $\frac{1}{3}$ of its breadth centrally is cut away so that objects can be viewed either against the left or right edge of this aperture.

The distance between the peep-hole and the centre of the sight-vane is 8 inches and the sight-vane from the centre upwards and downwards is graduated on the left side in degrees and on the right to natural tangents to an arc of 8 inches.

The use of the instrument is very simple. It is placed on the table and usually the right edge of the aperture, that for natural tangents, is brought on the object so that when the observer looks through the peep hole the object is seen to be cut at or near a certain division of the scale. The bubble is now brought to the centre and a reading is taken; let it be ·024. This represents the natural tangent of the angle which multiplied by the horizontal distance taken off the plan and when corrected for curvature and refraction, will give the difference of height between the instrument and the object. Over distances up to 5 miles a properly adjusted clinometer will give mean readings to within 5 feet. The distances in feet between the instrument and object observed is usually taken off a cardboard scale on which the curvature and refraction correction is also ruled at intervals (see para. 162).

To adjust the instrument.—With a theodolite or level at hand to set out a level line it is only necessary to adjust the bubble to the line of sight but as the instrument is generally used on topograpical work with fixed stations and heights, a simpler method suggests itself. The instrument is set up on a planetable over a known station mark with the height value given. To this known height is added the difference of height between the mark "in situ" and the height of the peep hole when the height of the peep hole is obtained. From the plottings on the table one or more other points are selected with given heights and as the horizontal linear distance is known so also is the correction for curvature and refraction.

Since difference of height between A and B = natural tangent of the angle between A and B × horizontal distance between A and B ± curvature and refraction (in this case since the object at B is observed to and the height of A deduced from B curvature and refraction is minus) thus the natural tangent of the angle is known. With the milled head screw make the instrument read this natural tangent and if the bubble is not in the centre of its run then correct it by the bubble nuts.

Example.—Height of station A = 1,440
„ „ „ B = 1,765
„ „ „ C = 1,420

and distance A to B = 10,000 feet and A to C = 6,000 feet. Height of eye = 4 feet and therefore height of instrument at A = 1,444. By calculation the natural tangent of B = +·032 and of C = − ·004 and if the instrument does not read these values the bubble is incorrect, so elevate or depress the peep hole to obtain these values and correct the bubble accordingly.

In using a tangent clinometer it should be lifted by its base, *never* by its vanes. The vanes should be perpendicular and as a test the distance between the peephole and the sight vane should be 8 inches directly across. In choosing a tangent clinometer select one in which the bubble is fairly long and sensitive though not too much so and which has the peep hole just large enough to admit of no parallax. A large peephole admits of a great deal of latitude in observation in that the object cannot properly be located at a definite reading.

In the example the value ·032 is read as ·03 line and an approximation of ·002 above it. This approximation becomes a simple one with practice but there exists a device by which the peephole is raised by a micrometre screw which makes such an approximation more accurate.

102. **The Aneroid Barometer.**—The mechanism of an aneroid barometer is explained in most books on physics and only the precautions to be taken in registering readings and the requiste formulæ are here given.

A good working size of instrument is a 5 inch with a range of 5,000 to 6,000 feet. Aneroids must be carefully handled and carried and are really only true within a certain limit when the readings are simultaneous or are taken at short intervals of time. They are compensated for internal temperature of instrument but great reliance should not be placed on this and they should be compared as often as possible with a standard barometer. On most aneroid barometers the zero of the altitude scale is at 31 inches of the scale corresponding to the mercury column. Aneroids when compared with a standard mercury barometer usually have an error which can be considered an index error or the screw at the back of the box can be turned to regulate the pointing of the needle. Heights to within 10 feet are possible with great care.

Aneroids are more reliable when used on uphill journeys as the atmospheric pressure decreases and the spring relaxes; on the other hand when the reverse is the case and the tension on the spring increases the instrument takes some time to settle down. Readings must always be

taken with the instrument at each station either held vertical or horizontal and it should be tapped gently before reading to make sure the chain gear is working properly.

There are several corrections necessary in barometric levelling such as temperature, changes of instrument and stations, corrections for latitude and decrease of gravity on the vertical, but with the aneroid, and for the ordinary purposes of the engineer, as the aneroid is compensated for internal temperature of instrument only the correction for air temperature at different stations will be considered, that is, if t is the temperature of the instrument at the lower station where the instrument reads H inches and t' the temperature of the higher station where the instrument reads h inches then according to one formula we get (i) D the difference in height $=60158 \cdot 6 \, (\log H - \log h) \times \left(1 + \frac{t + t' - 64^\circ}{900}\right)$.

(ii) due to Airy; $D = 62759 \, (\log H - \log h) \times \left(1 + \frac{t + t' - 100^\circ}{1000}\right)$; that is the difference in two altitude readings is corrected for temperature by $\frac{1}{1000}$ part for every degree the sum of the temperatures when the sum exceeds 100 ° F.

For rough calculations the following might be useful—

(iii) $D = 55000 \frac{H-h}{H+h} + \frac{1}{500} D$ (for each degree of mean temperature) above 55° F.

(iv) For approximate values only, $D = 55000 \frac{H-h}{H+h}$

Example let $H = 30 \cdot 00$ inches

$h = 28 \cdot 00$ inches

$t = 90^\circ$

$t' = 64^\circ$

Then by formula (i) we obtain

$$D = 60158 \cdot 6 \, (1 \cdot 47712 - 1 \cdot 44716) \left(1 + \frac{t + t' - 64^\circ}{900}\right)$$

$$= 60158 \cdot 6 \times \cdot 02996 + \left(1 + \tfrac{1}{10}\right)$$

$$= 1982 \cdot 6 \text{ feet.}$$

By formula (ii) $D = 62759 \times \cdot 02996 \, (1 + \cdot 054)$

$$\text{or } \log D = \log 62759 + \log \cdot 02996 + \log 1 \cdot 054$$

$$= 4 \cdot 79775 + \bar{2} \cdot 47654 + 0 \cdot 02284$$

$$\therefore D = 1982 \cdot 1 \text{ feet}$$

By forumla iii) $D = 55000 \times \frac{1}{29} + \frac{1}{500} \times D \times 22^\circ$

$$= 1895 \cdot 2 + \frac{22}{500} \times 1895$$

$$= 1895 \cdot 2 + 83 \cdot 4$$

$$= 1978 \cdot 5$$

By considering $D = 1978 \cdot 6$ we can bring this result still closer by substituting the value $1978 \cdot 6$ in the second part of the equation and obtain $1895 \cdot 2 + 88 = 1983$ feet and again obtain the limiting value 1984 feet.

CHAPTER V.

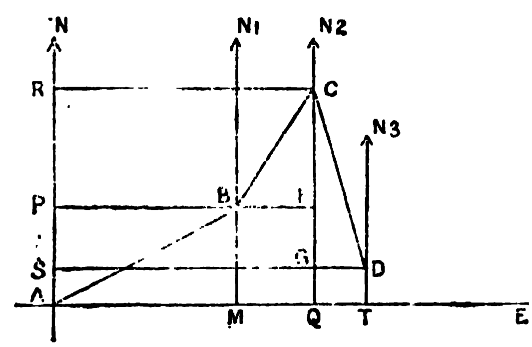
TRAVERSING AND ITS COMPUTATIONS

AND CITY SURVEYING.

103. A **Traverse** may be defined as a circuitous route performed on leaving any place on the earth's surface, by stages of straight lines, in different directions, and of various lengths, with a view to arriving at any other place situated in any direction with reference to the former, and at any distance therefrom which cannot be reached in the direction of the shortest line connecting them.

Let AB, BC, CD, (*Fig.* 63.) be the first three lines of a traverse, and NA the meridian, which may be either the true or the magnetic meridian, or even some direction making a given angle with some well defined object observed at the starting point. The bearing NAB was first observed, then AB measured, then the angle* ABC read, then BC measured, then BCD read, then CD measured, and so on.

Fig. 56.



By the ordinary method of plotting AB would first have to be protracted, its distance laid off, and thus the point B is found; similarly from the point B, BC is protracted, and its distance laid off, the point D in a similar manner is arrived at, and so on.

Now, if any error arises in the *protraction* of the angles NAB, ABC, BCD, &c., that error is carried on throughout. To obviate this repetition of error the method of co-ordinates has been restored to.

Draw AE at right angles to the meridian NA; also the lines N_1BM, N_2CQ, N_3DT parallel to NA, and CR, FBP, DGS, parallel to AE. Now if the distances AM and MB are known, by setting off AM along AE and MB at right angles to AE the point B is at once found. Similarly with the points C and D, and so on. But the laying off of the co-ordinates AQ, QC of the point C is quite independent of those of the point B, as can be thus shown:—

The bearing of AB = the angle NAB=angle ABM.

* All angular instruments read angles according to the rotation of the hands of a clock.

Now AM=AB sin ABM, and MB=AB cos ABM ; consequently the co-ordinates of B, AM and MB are easily found.

N_1BC is the bearing of BC= angle BCF. In a similar manner BF and FC are found.

From the construction of the figure it will be seen that the co-ordinate AQ of the point C = AM + MQ = AM + BF, both of which are known similarly CQ, = CF + FQ = CF + BM ; therefore the co-ordinates of C are known, and therefore the point C can be laid down on paper perfectly independently of the point B. Similarly for D; AT = AQ + QT =AQ+GD, and DT =GQ = CQ − CG ; and so on

The distances BM, CQ, DT, &c., or in other words, their equals AP, AR, AS are known in **Gale's Traverse System** as *latitudes*, i.e., the distances North or South (in this case all North) of the point A on the meridian AN; and the distances AM, AQ, AT as *departures*, or longitudes, i.e., distances from A along AE East or West of A (in this case all East).

Gale's Traverse System, therefore, is a method of protracting by rectangular co-ordinates, and is applicable to any mode of surveying whatever such as Route Surveys, Railway Lines, Navigation Courses, and the like, where every station is fixed by the distances on the meridian and perpendicular.

Conditions.—When a traverse makes a complete circuit, i.e., returns to the starting point, there are three different *conditions* that must be fulfilled :—

1st.—That all the interior angles, together with four right angles, must be equal to twice as many right angles as the figure has sides. This is a little apt to mislead. *All* the angles must be *observed* ones and on returning to the starting point the interior angle between the last and first line of traverse must be *observed.*

2nd.—That the "Northings," or distance travelled North, must be equal to the "Southings," or distance returned South.

3rd.—That the "Eastings," or distance travelled East, must be equal to the "Westings," or distance returned West.

The first condition is proved in Euc. I., 32, Cor. 1, and a very little common-sense will at once perceive the correctness of the second and third conditions.

104. **Method of Surveying by Interior Angles.**—Let ABCDEFGHIJA (*Fig.* 57) represent a ten-sided polygon, which has to be surveyed, and let NAS be the magnetic meridian through A. Set up the theodolite at A, and observe the angle NAB; this angle is a magnetic *bearing* of AB to the meridian. Then set up the instrument in succession at B, C, &c., and

proceeding *anti-clock-wise* observe all the interior angles ABC, BCD, &c., and finally set the instrument again at A, and observe the inward angle JAB. In this case, as it is a ten-sided figure, the sum of the included angles must equal 1440°, ($180° \times 10 - 360° = 1440°$).

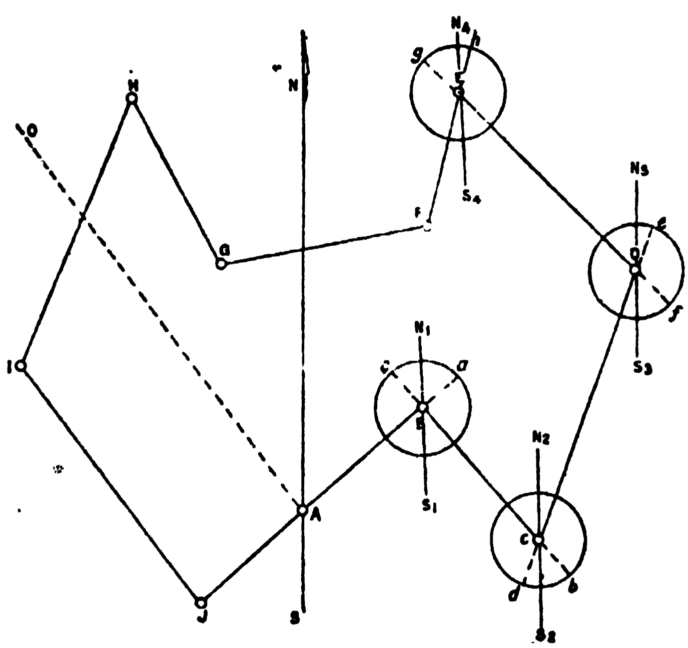
In practice it will be found that this result cannot be exactly attained, and that the sum of the angles will generally amount to two or three minutes more or less; to meet this, a correction of one minute in every four or five angles, additive or subtractive as the case may need, is generally necessary to obtain the result required.

The bearings of the various sides are found by means of the following rule:—

To the bearing of the line preceding that of which the bearing is sought add the inward angle formed by these two lines, and the sum increased or diminished by 180° *according as it may be less than, or in excess of,* 180°, *will be the bearing of the next line.*

Let the bearing of the line AB in the figure be given.

Fig. 57.



To find the bearing of the line BC.—Produce AB to a, and CB to c. The two meridians NS and N_1S_1 being parallel, the angle ABS_1 is equal to the angle NAB; if to the angle ABS_1 the interior angle of polygon ABC, or its equivalent in arc is added, the angle formed by the line CB with the meridian N_1S_1 or angle S_1BC is obtained; if then the angle S_1BN_1 or 180° be deducted from this, thus reversing the direction of the line, the angle N_1BC is left, and this is the bearing of the line BC with the Meridian N_1S_1.

To find the bearing of the line CD.—Produce BC to *b*, and DC to *d*. The two meridians N_1S_1 and N_2S_2 being parallel, the angles N_1BC and BCS_2 are equal. If to the angle BCS_2 is added, the interior angle of the polygon BCD, the angle formed by the line DC with the meridian N_2S_2 or angle S_2CD results, if then the angle S_2CN_2 or 180° be deducted from this, thus reversing the direction of the line, the angle N_2CD is left, which is the bearing of the line CD with meridian N_2S_2.

To find the bearing of the line DE.—Produce CD to *e*, and ED to *f*. The two meridians N_2S_2 and N_3S_3 being parallel, the angles N_2CD and N_3De are equal. If to the angle N_3De or arc N_3e, the interior angle of the polygon CDE, or its equivalent in arc *ef*, is added, the angle formed by the line ED with the meridian N_3S_3 or arc N_3ef results; if then the angle *f*DE or 180° be added to this, thus reversing the direction of the line the angle N_3DE is obtained, which is the bearing of the line DE with the meridian N_3S_3.

To find the bearing of the line EF.—Produce DE to *g*, and EF to *h*. The two meridians N_3S_3 and N_4S_4 being parallel, the angles N_3DE and N_4Eg are equal. If to the angle N_4Eg or arc N_4hS_4g, is added the interior angle of the polygon DEF, or its equivalent in arc gN_4h the angle formed by the line FE with with the meridian N_4S_4, or arc $N_4hS_4gN_4h$ results, from which if the angle *h*EF or 180° be deducted, thus reversing the direction of the line, the angle N_4EF is left, which is the bearing of the line EF with the meridian N_4S_4.

And so on, this rule may be carried through every line of the polygon as far as the last line JA, when its bearing, added to the interior angle JAB+or−180°, as the case may require, will give the original starting bearing of the line AB.

If as will occasionally happen the sum of the preceding bearing and forward angle diminished by 180° amounts to more than 360°, deduct 360° from the total—the remainder will be the bearing of the line. A moment's consideration will show the reason for this, for as the horizon is only divided into 360° parts, and as 0 and 360 represent the same division, it is evident that as soon as the needle swings past the division 360 the small numbers must begin again.

Also, the columns of latitude and departure will not be found to balance exactly, for inaccuracies must arise from observations and chaining, in the field, which no care could obviate. On the Revenue Survey, the amount of error allowed is one link in ten chains, additive or subtractive, from the sums of the Northings and Southings to correct the latitude, and the sums of the Eastings and Westings to correct the departure.

This error must be apportioned among each of the distances of the survey by the following proportions, viz :—

As the sum of all the measured distances is to the whole error, so is each distance to its correction (see also para. 122) but as this is a somewhat lengthy process it is found sufficient to balance all ordinary traverses by proportioning the error with reference to the total error in latitude or in departure—as in example (Traverse Form A) where ·2 feet departure (cols. 9a and 10a) is to be distributed equally to the two greatest departures plus and minus, instead of going into the second place of decimals which is beyond the limits of accuracy of the chain measures in the field work.

This must be done independently for the latitudes and also for the departures, and is entered in a column appropriated to each, called the North and South correction, and the East and West correction; the correction, thus determined, must be placed collaterally with the distance to which it refers, without distinguishing as to North, South, East or West.

Having found the several corrections for each of the latitude and departures, add them together severally, and see whether their total agrees with the whole error, and if so, proceed to allot the corrections. If the error be an excess of Northings, subtract each correction from its collateral Northing, or add it to the collateral Southing; if an excess of Easting add to the Westing and subtract from the Easting; the sums of the corrected latitudes and departures will then be found exactly to agree.

105. **The Traverse Table.**—On the next page is given the Traverse Table of an actual survey by interior angles (see Form A).

Col. 1—Contains the figures representing the stations of the Survey.

Col. 2—Contains the inward angles.

Col. 2A—Contains the corections to be made in those angles so that the *first condition*, para. 104 may be fulfilled.

Col. 3—Contains the bearings of the several lines deduced, as per rule, para. 104.

Col. 4—Contains the reduced bearings, i.e., the angle adopted to tables of logarithmic sines and cosines.

Col. 5—Contains the distances as measured in the field.

Col. 6—Contains the cardinal direction of each line.

Cols. 7, 8—Contain the distance on the meridian between every two stations.

Cols. 9, 10—Contain the departure of each station from the meridian of the preceding one.

Cols. a, a, a, a—Contain the corrections necessary so that the *second* and *third conditions*, para. 104, may be fulfilled.

Col. 11—Contains the distances on the meridian of each station from the origin. The letters N. and S. showing whether the several stations are situated North or South of the origin.

Col. 12—Contains the departure of each station from the first in the series, the letters E. and W. showing whether the several stations are East or West of the origin.

Col. 13—Contains the successive ordinates of departures.

Cols. 14 and 15—Contains the values for double areas.

Col 16—Column for remarks. In triangulation when stations are set up as a traverse and heights of station are known, also in traversing when the traverse pegs have been levelled to, this column can be also utilised for the record of such heights.

Columns 1, 2 *and* 5.—Are taken from the field book.

Column 2.—The sum of the angles in col. 2 is too much by 40 secs. Since the theodolite issued is supposed to be one graduated to read 20″ then 40 secs. should be subtracted in two sums of 20″ each. The error has been applied in the correction col. 2A to equidistant stations E and I but it would be really more correct to apply the correction to the angle between the two shortest lines or at stations F and E.

Column 3.—The bearing of the first line AB that is A to B was observed to be 199° 48′ 00″. This value is placed opposite B in col. 3. The bearings of the other lines are found according to the rule given and to take a concrete example are as follows.

Example.—Bearing of the line E to F or EF $= 75° \ 51' \ 00'' + 182° \ 32' \ 00'' - 180° \ 0' \ 0'' = 78° \ 23' \ 00''$. Bearing of the line H to I or HI $= 82° \ 50' \ 30'' + 49° \ 50' \ 00'' + 180° \ 0' \ 0'' = 312° \ 40' \ 30''$.

Note the check at station A for closing bearing $= 192° \cdot 48' \cdot 00''$ which is a check on the arithmetic and corrections applied.

Column 4.—Since ordinary log tables give values up to 90° only, it is necessary that the bearings in column 3 are reduced and since by Trigonometry Sin A=Sin (180—A) also Sin A=—(Sin 360—A) and Cos A=Cos (360—A). Then when the bearing in column 3 is less than 90° there is no change; when the bearing is greater than 90° and less than 180° subtract the bearing from 180°; when the bearing is greater than 180° and less than 270°, subtract 180° from the bearing; when the bearing is greater than 270° and less than 360° subtract the bearing from 360°. For examples of the above in the form compare columns 3 and 4 opposite stations F, G, E and A.

Column 6.—Shows the cardinal direction, that is, in which quadrant the direction of the line lies and as the true directions of the lines are found as bearings in column 3 therefore the cardinal direction is with reference to the values in column 3 and not with those in column 4. In the form given the bearing of F G or F to G is 90°· 41′· 30″ therefore the direction of the line FG lies SE from the point F; similarly direction A to B is SW from A &c.

The form has now been filled up as far it can go without the help of log tables and the surveyor should here determine what accuracy in plotting is necessary for his work and scale. If the scale will not permit of a plot being made to the decimal part of a foot then 4 places for logs will be sufficient, but if as in the case of the example in the form plotting is possible to the decimal point of a foot as in most city surveys then 5 places of logs for sides and angles will be necessary.

Again if the distances between stations are only correct to the nearest foot it is evident that any calculation leading to a greater accuracy will only produce a fictitious closing value.

Columns 7, 8, 9, 10.—These columns give the latitude and departure of each distance. Referring to fig 56 AB is a given distance and ABM (=NAB) its bearing. Here, BM is the latitude of B, or its distance from A along the meridian, and AM is the departure of B or its distance from A along the perpendicular to the meridian.

By Trigonometry AM and BM can at once be found,

for BM (latitude)=AB (distance) × cos ABM (bearing),

and AM (departure)=AB (distance) × sin ABM (bearing) or using logarithms,

log latitude=log distance + log cos bearing − 10,

and log departure=log distance+log sin bearing −10.

Thus in the lower compartment of form the middle line cantains the values of log distances and the log cos bearing and log sin bearing diminished by 10 are written as shown, both values being extracted from the log book at the same time. The computation for latitude is made upwards and that of departure downwards, as this takes up less room.

The antilog values of latitude and departure are deduced and placed in columns 8 and 10 in accordance with their cardinal direction and since these values are those of B from A (in this case the origin) therefore the values appear on the line for station B etc., etc.

When there is much traversing to be done this method of computation would take up too much time and traverse tables should be used. Traverse tables showing the differences of latitude and departure to every minute of the quadrant by Major-General Boileau, R. E., are perhaps the best known and the procedure is as follows:—

Take the case of the co-ordinates for station B.

Look up in the tables 19° 48′ and since the latitude and departure for 4191·9 feet are required this quantity in the tables will have to be split up

into 1000·0 + 400·0 + 90 ·0 + 1·0 + ·9 = 1491·9 and for 1,000, 400, 90 etc., we obtain the following values.

Latitude.	*Departure.*
940·88	338·73
376·35	135·50
84·68	30·49
·94	·34
·85	·30
1403·70	505·36

Columns a a a a.—It will be observed that the total north and south latitudes is zero or that there is no correction to be applied and that in departures there is a difference of ·4. In a previous paragraph mention has been made how this error should be distributed in proportion to distances but in this case since the error is so small we have + ·2 to be applied to the eastings and − ·2 to the westings and this is done by accrediting the greatest departures with ·1 foot a piece. The traverse is now considered to be *balanced.*

In balancing a traverse the error in closure includes all compensating errors and it would be more correct to distribute errors in measures made over uneven ground or under adverse circumstances. Linear measures are generally too long and so it is more correct to apply a greater minus than a plus correction; again a slight change in the bearing of a long line would affect the closure more than one in a short line and so also the bearing of a line at 45°, 135°, 225° and 315° would affect the latitudes and departures equally and in any other direction unequally.

Column 11.—This column is obtained from columns 7 and 8. The difference in latitude between stations A and B will be the total southing made by the line AB, consequently 1403·7 is the latitude of B since A is the origin. With the same argument since C is 704·6 south of B then the total southing of C from A is 1403·7 + 704·6 = 2108·3 and eventually it is found that the total southing of E from A is 3276·0. The point F however is in a direction north and therefore F is N of E so that F with reference to A is 3276·0 − 126·4 = S3149·6 and so on till the traverse returns to A when by rule the northing must equal the southing and thus the southing of I = 1059·5 is equal to the northing of A = 1059·5.

Column 12.—The values in this column are found in exactly the same manner as the values in column 11 except that easting and westings are dealt with and in the final line as proof, the easting of I = 1308·2 is balanced by the westing of A = 1308·3 − ·1 correction = 1308·2.

Column 13.—Is a column for successive ordinates by which the double area is obtained. The successive ordinates are found as follows. Add the departures in pairs algebraically considering East being positive and

West being negative and enter in column 13. The values in column 12 for A and B are 0 and W 505·4, thus W 505·4 is entered in column 13 opposite station B. The successive ordinates of B and C are both westings therefore their signs being both minus their result is W 697·2. The successive ordinates for C and D are W 191·8 and E 233·7 and since the signs are opposite and the easting or plus direction is the greater then the result is written as E 41·9. In this column the E and W must be carefully entered as whether the successive ordinate is E or W it becomes plus or minus and influences the next calculation for columns 14 and 15.

Columns 14 *and* 15.—Are for double areas and are found as follows :—

The successive ordinate is multiplied by the distance on the meridian pertaining to that ordinate. Distances on the meridian are considered as plus or minus according as they are north or south so the algebraical product with due consideration of signs of columns 7, 8, and 13 is entered in column 14 or 15.

Example W 505·4 × S1403·7 = − 505·4 × − 1403·7.
= + 709,435 for line B.

And similarly + 233·7 × − 522·0 = −21,870 for line D etc.

Columns. 14 *and* 15—Are totalled and the minus double area is subtracted from the plus double area and the result is the double area of the enclosed figure in square feet which can be reduced to acres (for proof, see para. 118).

106. **Traverse Table for survey by bearings from an actual or assumed Meridian.**—The following example of a Traverse Table (Form B) is taken from a survey executed by students of the Thomason College. It should, however, be noted that this form may require modification according to the conditions under which the survey is to be carried out.

Col. 1.—Contains the figures or letters representing the stations of the survey.

Col. 2.—Contains the inward angles deduced from the bearings as a check.

Col. 3.—Contains the bearings read in the field with the correction of 180° applied to alternate bearings as stated in the heading. In this connection it should be noted that calculations should never occur in the Field-book. The Field-book should be a record of the actual observations, and necessary corrections should be afterwards applied, except the reduction of chain measures to the horizontal.

Col. 4.—Contains the cardinal direction of each line.

Col. 5.—Contains the bearings reduced for logarithmic sine and cosine tables. Any correction for change of meridian should be applied before making the entry in this column. This latter correction is necessary when it is required to plot the survey to a meridian differing from that on which the field work was carried out.

Col. 6.—Contains the distances measured in the field or measures reduced to the horizontal.

Cols. 7 *and* 8.—Contain the calculations for latitude and departure the L cos. and L sin. given being those of the reduced bearing of the line.

Cols. 9, 10, 11, 12.—**Contain the differences of latitude and departure for each distance. These latitudes and departures are first entered in black as calculated, the error is then apportioned according to the rule given in para. 104, and the corrected latitudes and departures are then entered in red above the originals.**

Cols. 13 *and* 14. —Contain the latitude and departure of each station referred to the origin from which the survey is to be plotted. These latitudes and departures are simply the algebraic sum of those given in Cols. 9, 10, 11, 12, up to the point for which they are taken

TRAVERSE FORM (B).

The bearings of the alternate stations, instead of being the actual bearing read off on limb of the theodolite have been increased or reduced by 180° vide C and E.

Under the heading " Reduced Bearing " should be entered the bearing reduced for logarithmic calculation. Any correction for change of meridian should also be applied before entering the bearing in this column.

Station	Deduced inward angles.			These entries are reckoned from starting end of distance.										Difference of latitude and departure for each distance.								Difference of Latitude and Departure of each station, referred to meridian of Station.			
				Bearing on limb theodolite.			Cardinal direction.	Reduced bearing.			Distance measured.	Logs of distance and cosine.	Logs of distance and sine.	Latitude.				Departure.				Latitude.		Departure.	
														North.	Cor	South.	Cor.	East.	Cor.	West.	Cor.	N. or S.		E. or W.	
	2			3			4	5			6	7	8	9		10		11		12		13		14	
	°	′	″	°	′	″		°	′	″															
..	...	...	..	...	...	...	...	...	...	...	...	3 1679	3·1679												
												$\bar{1}$·9995	$\bar{2}$·6923												
				182	40	20	SW	2	49	20	1,472	3·1674	$\bar{1}$·8602	...	...	1,470	...	...	..	73	...	S	1,470	W	73
B ..	68	52	10	...	..	...	...	...	..	...	...	3·0366	3·0366												
												$\bar{2}$·7119	$\bar{1}$·9994												
				272	67	0	NW	87	2	50	1,008	$\bar{1}$·7885	3·0360	26	...	...	..	...	...	1,087	2	S	1,414	W	1,159
..	86	37	10	...	...	...	...	...	..	...	...	3·3487	3·3487												
												$\bar{1}$·9973	$\bar{1}$·0426												
				6	20	40	NE	6	20	0	2,232	3·3460	2·3913	2,220	...	...	...	246	...	..	...	N	806	W	9,153
D ...	50	7	20	...	..	..	...	...	...	...	...	2·9552	2·9552												
												$\bar{1}$·8585	$\bar{1}$·8401												
				135	12	40	SE	43	47	20	910	2·8137	2·7953	...	...	661	..	624	...	...	...	N	155	W	28
E ...	197	59	50	...	...	...	...	...	...	...	...	2·5159	2·5159												
												$\bar{1}$·6746	$\bar{1}$·9451												
				118	12	50	SE	61	47	10	328	2·1905	2·4610	...	...	155	...	289	...	...	...	...	0	...	
..	115	23	30																						
Total	540	0	0	...	...	...	...	...	...	..	5,942	...	...	2,276	...	2,276	...	1,159	..	1,160	1	...	... ...		..
														2,276	...	...	...	1,160	..	...	...	...	Ratio of error.		1
Proof of angles 5 × 180—360 = 500													Error ...	0	...	...	...	—1	...	...	—1	...			5,942

106. The **bearing method** of traversing is as follows :—

Consider fig. 57 and let the theodolite be set up at A and with the two plates clamped at zero let the object glass of the theodolite be brought by the compass into the plane of the magnetic meridian by means of the lower plate which is now clamped. Next release the upper plate and read the forward station B on vernier A (that is the vernier below the vertical arc). The reading will be the bearing of the line AB. Since the forward station B had

to be intersected by means of the slow motion screw the upper plate is therefore clamped and must remain clamped. The instrument is now taken to station B and by loosening the lower plate the wires are made to intersect the back station A by clamping the lower plate and using the lower slow motion screw. The reading of A vernier should be the same as it was at station A and it should be checked to see that no movement or displacement has taken place. The upper plate is released and the telescope directed to C the forward station and C is intersected by clamping the upper plate and using the slow motion screw.

Now the angle NAB=angle ABS_1 since N_1 S_1 is parallel to N S but the zero at B is in a direction BS_1 opposite to BN_1 or a difference of 180° and therefore the direction BC is the bearing of C from B plus or minus 180° unless B vernier is read or the instrument is transitted. This difference of 180° will occur at every even number station and the last bearing on closing the traverse should agree with the original starting bearing except that this allowance of 180° must be made if it happens to be an even number station. Distances are measured between stations.

107. The **inward angle** method of traversing is as follows. The direction of proceeding station by station should be counter clockwise. Set up the theodolite at A and level it (see fig. 57) and if the direction A to J or A to B has not been calculated by an azimuth observation or given as a bearing from another traverse line, clamp the two plates to zero and rotate telescope till the object glass end points to magnetic N by the compass using the lower plate and slow motion screw. The compass if of the rectangular pattern, as is generally the case with modern theodolites, should be taken off and put away. Next release the upper plate and read the back station J and then the forward station B the lower plate remaining clamped throughout the whole of this operation, the readings being read on A vernier or the vernier placed under the vertical arc. As B will have been read by clamping the upper plate and manipulating the slow motion screw it stands to reason that the upper plate now remains clamped. Let the readings to J and B according to the field book record (see fig. 58, p. 151) be 220° 15′ 20″ and 50° 31′ 40″ respectively. These readings are magnetic bearings of J and B and the inward angle at A between J and B is found by subtracting 220°. 15′·20″ from 50°·31′·40″ (+360°) and is 190° 16′ 20″ for the first round.

The lower plate is now unclamped and the telescope is turned to the back station J and the flag at J is intersected by clamping the lower plate and using the slow motion screw. The reading of vernier should now be examined and it should read 50° 31′ 40″ that is, that the forward reading has

been set on to the back flag. Now unclamp the upper plate and intersect the forward flag and let the reading be 240° 48′ 20.″ The second round thus gives an inward angle of 190° 16′ 40″ and the mean of the two rounds will be 190° 16′ 30.″ In the revenue work of the Survey of India it is the custom to also observe and record the outward angle which subtracted from 360° should agree within certain limits with the mean of the inward angles. This angle is a further check but is really taken for the purpose of simplifying the computations if a traverse has to be set up in a clockwise direction.

The distance between A and B is now measured and is found to be 476·6 feet. A record of crossings and offsets to near detail is also kept. The instrument is now taken and carefully centred over the next mark or station B and levelled. The two plates are clamped but not to read anything in particular. Let the reading on A vernier be 120° 41′ 40″. The telescope is turned by means of the lower plate towards station A the back station, and the intersection is made by clamping the lower plate and using the lower plate tangent or slow motion screw. The upper plate is released and the telescope pointed to C the forward station and C is intersected by clamping the upper plate and using the upper plate slow motion screw. Let the reading on vernier A be 29° 51′ 00″. The inward angle resulting for the first round is therefore 269° 09′ 20″. The lower plate is now unclamped and the telescope turned to the back station A and the lower plate is clamped and intersection is made with the lower plate slow motion screw and thus A is intersected with a reading of 29° 51′ 00″ which was the reading of the forward station. The vernier reading is examined to see that no shift has taken place. The upper plate is now unclamped and the telescope turned towards C, and C is intersected by clamping the upper plate and using the upper plate slow motion screw. Let the reading be 299° 00′ 20″. The inward angle of the second round is therefore 269° 09′ 20″ and the mean inward angle to be accepted for computation and entry in the traverse form (A) column 2, is 269° 09′ 20″ and so on station by station.

The specimen in fig. 58, page 150 is an example of a field book by the **inward angle method.** Recording is to be done *in ink* from bottom of the page upwards.

108. In previous editions of this book the bearing method has been recommended as it is said (1) to eliminate graduation errors since readings are made on all portions of the plate and this would be true if the inward angle method confined itself to setting on the back station each time with

the vernier clamped to 0°, but it has been shown that this is, not only not necessary, but time is saved if the starting reading viz. 120° 41′40″ at station B (see field book) is as given at the time of clamping the plates. (2) It is said to have fewer readings therefore fewer reading errors. This again is not so, as the setting of the forward reading on the back flag by the inward angle method equalises matters. Any extra number of readings made by the inward angle method are for means of checking and verification of the angle and this verification is done by the second round being taken over a different part of the graduated plate which cannot happen with the bearing method. (3) With the bearing method supposing the bearing of a line JK was read incorrectly and entered and recorded as 278° instead of 279.° The reader will understand that this error of 1° will not be carried forward in the observational work as the plates are clamped at 279° and unless the error is detected at the time and the record corrected the subsequent bearings will still be correct and the traverse might close quite correctly in bearings, but when balanced, if the line JK. happened to be a fairly long line, the traverse will disclose a gross error in Northings and Southings, Eastings and Westings. Where the error has occurred cannot be detected and it might probably be too late to rerun the line. Therefore the argument that by the bearing method any error in reading a bearing effects only the bearing to which the bearing pertains may be considered to be rather against than for the retention of this method in preference to the inward angle method. (4) By the inward angle method although the final error in closing includes all accumulative *errors* yet these errors can be dispersed throughout the traverse since the angles at each station have heen observed with as much accuracy as is necessary and without any chance of a *mistake.* It is also to be remembered that the mistake of 1° might have been caused by the traverser manipulating the wrong tangent screw, not an unlikely thing to happen when one's mind is distracted, as it often is, by chainmen and flagmen disregarding instructions. (5) Lastly it is argued that the compass if watched will disclose any mistakes. This takes it for granted that the compass is of the circular pattern sunk in to the upper plate (a relic of 25 years ago and now not made in this manner by first class instrument makers) and that local attraction at different places along the line is constant. (6) To dispense with the difference of 180° at even stations B vernier might be read at station B for direction of C or the instrument might be transitted and A vernier read. Unfortunately neither of these are free from error as in the first instance any difference in the setting of the verniers (in a 2 vernier instrument) produces an error and in the second instance the collimation error for horizontal angles creeps in as no instrument is

strictly free from collimation error and in any case repeated examination and testing for such would be necessary and laborious.

To sum up, any survey system or method which permits of *mistakes* creeping into records must be condemned. The bearing method may be good enough in the hands of a careful and reliable man traversing over a small area and an independent one at that, but when a surveyor has to deal with long lines, and has perhaps to depend on, a not too highly skilled agency to help him, he cannot afford to adopt any system but a self-checking one and it has been found in India, at any rate, that the inward angle system, with at least two angles agreeing, within certain limits, is the best.

109. The following steps therefore are to be followed in measuring inward angles of a traverse (see fig. 32.)

(1) Level up theodolite after thoroughly centering it over station dot.
(2) Intersect back flag by clamping C_1 and using T_1 (C_2 having been previously clamped.)
(3) Read and record value of reading of A vernier.
(4) Unclamp C_2 and intersect forward flag by using T_2.
(5) Read and record value of reading on A vernier.
(6) Unclamp C_1 and intersect back flag by using T_1.
(7) Examine reading which should be as given under (5).
(8) Unclamp C_2 and intersect forward flag by using T_2.
(9) Read and record value of reading on A vernier.
(10) Subtract 3 from 5 and 5 from 9 and if the angles thus deduced disagree by more than the graduation of the instrument continue till there is a satisfactory agreement.

110. **Concerning chains and chaining and measures generally.**—For ordinary work the Gunter (66′) or the 100′ chain is used in measuring the distances between stations (see also para. 20). The Gunter chain is one of 66′ in length, is lighter and handier but has this disadvantage over the 100′ chain, in that there are more chain lengths, and therefore more pitching of arrows and greater liability to accumulative error. On more or less flat open ground it cannot be therefore as accurate in measuring distances as the 100′ chain.

In traversing two chains should be used one a Gunter and one, a 100′ chain. The Gunter chain being only as a check on the 100′ chain for the whole distance and therefore the chainmen, not so expert as measurers, are those on the 66′ chain. The traverser should follow the 100′ chain keeping an eye on the alignment of both chains and the correct vertical pitching of all arrows. The traverser must always have with him in his camp a steel tape or a tested 100′ chain in order that he may, morning and

evening of a day's work, check and correct his working chains. The chains used on work should be well tried old chains, which do not stretch so readily as new ones. The chain given for testing should never be used on the work and the steel band should be kept dry and clean and when put away for a period, should be oiled and wiped.

The measures of the 100′ foot chain are reduced to the 66′ chain as follows :—

13·66= recorded long chain measures.
6·83= ½ ditto.

20·49 Total

·205 add the first three figures of total moved 2 places to the right

20·695 = reduced chain measure in short chains.

The record of the lengths of the chains at the commencement and end of the work must be made daily so that the correct chain values for computation may be reduced. The mean of the short and long chain is not to be used, but the length of the long chain only. The difference between the short and long chains measures should not be more than $\frac{1}{1000}$.

111. When traversing of greater exactitude than $\frac{1}{5000}$ is required as would be necessary for City Surveys the steel tape standardised to a certain temperature must be used (see paragraph 127.) If a greater accuracy than $\frac{1}{10000}$ the line must be staked out and the tops of the stakes or pegs levelled for different sections. Working along streets with a steel band and spring balance handle for tension pull, the reduction of measures for temperature changes and slope and with a theodolite graduated to read 20 secs. there should be not much difficulty in obtaining accuracy to $\frac{1}{17000}$ (see paragraph 122). Beyond this limit the cost of survey would increase rapidly and it is worth considering whether the increased cost is compensated for by the increased accuracy.

112. Over uneven ground the changes of slope are best measured with a wooden clinometer or better still by an Abney's level, the readings being made to a disc held at the other end of the slope at the height of the observer's eye. If an accuracy in chaining of $\frac{1}{1000}$ only is required the chainmen should employ the method of "cutting the chain" that is, holding the chain level by short lengths and plumbing the measure to the ground surface and if the ground surface is more or less an even slope the horizontal measure can be obtained since it is equal to the measured distance × by the cosine of the angle of slope.

113. For accurate work over long distances the crinoline chain has been used. The crinoline chain is of invar metal and is in 5 sections of 66 feet or 330 feet in total length. The plains of northern India have been traversed with this chain in preference to an expensive system of triangulation.

114. The chain is gathered up in the following manner. Hold the 50 foot tablet in the right hand and drag the chain till it doubles itself and the handles come together. From the 50 foot tablet end bundle up the chain two links at a time when its shape will be that of a reel or hour glass. The chain should not be undone except systematically. The two handles are taken in the left hand and the chain is thrown forward with the right hand and it will be found by walking a few yards, holding the handles, that the chain will unravel itself freely.

115. **Errors in chaining.**—The following are the errors in chaining. (1) Errors in alignment, (2) errors in pitching arrows, (3) errors due to links being bent or doubled, (4) errors due to the small link connections being pulled till they gape, (5) errors due to the small link connections taking up a crosswise instead of a lengthwise position on the chain, (6) mistakes due to counting the number of chains measured and failure to notice that an arrow is missing. For full particulars the reader is referred to paragraph 20.

116. *Tape measures.* Each of the following errors in a 100 foot tape (steel) length will give an error of $\frac{1}{10,000}$.

(1) Length of tape giving a difference of ⅛th inch from the standard.
(2) Error in marking or plumbing ⅛th inch.
(3) Error in reading ⅛th inch.
(4) Error in sag or the middle of the tape being 8 inches lower than the ends.
(5) Temperature correction for every 16° (approx).
(6) Tape stretched loosely so that the centre is 8 inches out of line.
(7) The end of the tape being 16 inches out of alignment.
(8) For every 16 lb pull.
(9) Tape not horizontal or one end 16 inches above or below the other.

(The reader will notice that the above values are either reciprocals or multiples of 8 and as such are as nearly correct as will be found necessary).

1 is accumulative + or − and the constant is to be applied to correct it.
5 is do do do do do

4, 6, 7, 9 are accumulative + and can be avoided and in flat areas need not be considered.

8 is compensating and 2 and 3 are mistakes.

117. The field book (see example given in fig. 58) should be a neat and well kept record. It should be also systematic. The traverser must always remember that he may not be the computer of his work. The space between the two centre lines is for theodolite readings to stations and chain records of the line between stations only. On the right hand side the angles are written viz. 190° 16′ 20″ and 190° 16′ 40″ and the mean angle is written up in red viz. 190° 16′ 30″. On the left hand side the vertical angles taken to forward and back stations usually to the mark on the flags denoting the mean or average height to which the instrument is set up are recorded and also any readings taken to conspicuous objects as intersected points. Readings to intersected points are not to be made except on the *last* setting of the instrument. If this is made a rule the computer will understand that the reading 223° 15′ "to palm" was with the theodolite set on the back flag at 50° 31′ 40″. This is an important point to remember. Chain measures corrected for slope should be entered in red. The vertical angles taken are for the purposes of chain reduction only. Traverses having height values can be run with a certain degree of accuracy, but the engineer would find such heights scarcely of any value for his work and a level should be employed in preference; this matter is therefore not treated on or dealt with further. The field book must be written from the bottom of the page upwards. All entries must be made in ink. A sketch plan and a well kept index is very important.

In connection with traversing and its computation the next few paras. are important.

117. *To find the distance and bearing between any two points on a traverse.*

In fig. 59, 1-2-3-4...10-11-12...18-19 are traverse stations and on the traverse being computed the following co-ordinates were found for stations 1, 10 and 18 respectively.

Feet.	Feet.	Feet.
N. 1018·6	N. 4367·5	N. 3410·9
E. 996·8	E. 2018·7	W. 608·3

Find the distances and bearings of 1 to 10, 10 to 18 and 18 to 1.

Let the first case be taken that of stations 1 and 10.

Through 10 draw a line 10 K parallel to the initial meridian and through 1 draw a line at right angles to the initial meridian to meet 10K in K.

Then the triangle 1 K 10 is a right-angled triangle of which the side 10K represents the difference of latitude between 10 and 1 and 1. K., which represents the departure between 10 and 1 and these are known and :—

10 K=3348·9 and K 1=1021·9

Now tan. angle 10 1 $K=\frac{3348\cdot9}{1021\cdot9}$

∴ angle 10 1 K=73° 1′ 51″

Again sine 10 1 $K=\frac{\text{side } 10\text{–}K}{\text{side } 1\text{–}10}\ \frac{3348\cdot9}{\text{side } 1\text{–}10}$

∴ Side 1·10=3501·5 feet

and similarly the other values for 10 and 18 can be found.

Now the angle M 1 K is a right angle or the bearing of K from station 1 is 90°.

and since the angle 10 1 K is equal to 73° 1′ 51″ ∴ the bearing of 1 to 10=16° 58′ 9″.

Similarly all the other bearings can be computed.

Now suppose x to be a point intersected from 1. 10 and 18. that is the angle at station 1 was found to be x. 1. 2. Since the bearing 1 to 2 is given in the computations of the traverse and the bearing 1 to 10 has been found therefore the angle x. 1. 10 is found and similarly the angle x. 10. 1 is found and thus in the triangle x. 10. 1 two angles and the adjacent side 10. 1 are known and therefore the triangle is solved and similarly the triangle 10. 18. x is solved and hence 10. x becomes a common side and the co-ordinates of x with respect to the origin can be computed.

118. **Areas.**—By successive ordinates or by double departures (DD).

The figure ABCDEFGHIA represents the plot of the traverse given in Form (A). Let the successive ordinates opposite A.B.C. etc. equal y_1, y_2, y_3, y_4, etc.

Let us consider the first double area = + 709,435 square feet which is twice the area ABB′ thus :—

(*a*) Twice area ABB′ = AB′ × BB′ = AB′ × ($y_1 + y_2$)
= —1,403·7 × (—505·4 + 0).
= —1,403·7 × —505·4.
= + 709,435 square feet.

(*b*) Twice area BB′C′C = area B″B′C′C″ + area BB′ x —C″ x C,
and since area BB″x= area C″xC by similar triangles.

∴ Twice area BB′C′C = area B″B′C′C″

but area BB′C′C = $\frac{y_2+y_3}{2}$ × B′C′

∴ Twice area BB′C′C = ($y_2 + y_3$) × B′C′
= —697·2 × —704·6.
= + 491,245 square feet.

(*c*) Area ODD′ = area GFD + area OD′FG,
and area GFD = area CHG (by similar triangles),
= area CC′O + area C′HGO.

$\therefore$ Area $ODD' =$ area $CC'O +$ area $C'HGO +$ area $OD'FG$,
$\qquad = $ area $CC'O +$ area of rectangle $C'HD'F$.

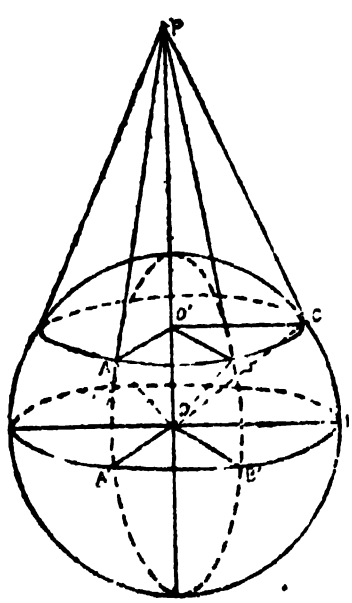
i. e. area $ODD' -$ area $CC'O =$ area of rectangle $C'HDF$.
$= JG \times B'D'$
$=$ Sum of CC' and $D'D$ with proper sign $\times B'D'$
$\overline{D'D - CC'} \times B'D'$

$\therefore$ Twice area $= (D'D - CC') \times B'D'$
$= (y^4 - y^3) \times B'D'$
$= (233{\cdot}7 - 191{\cdot}8) \times - 522{\cdot}0$
$= + 41{\cdot}9 \times - 522{\cdot}0$
$= - 21{,}870.$
etc., etc.

119. **Convergency of Meridians.**—It is usual in a traverse to suppose that the meridians of the stations are parallel to that of the starting station or origin. Provided a station is not far E or W of the origin the meridians of the station and of origin are practically parallel, though not actually so, as all meridians converge towards each other and meet at the poles. But when the departure (distance E or W of the origin) exceeds say 8 or 10 miles there is an appreciable convergency and a correction is necessary for converting apparent to true bearings.

The very slightly curved surface of the earth over which the traverse has been run may be supposed to be flat, and tangential to the sphere, within an area of say, 40 or 50 square miles.

Fig. 61.



Let the circle of the figure represent the terrestial sphere, O its centre and r its radius. Let ABC represent a parallel of geographical latitude λ, passing through a station B of the traverse. Let the meridian that passes through the origin of the traverse cut the parallel in A and let the meridians of A and B cut the equator in A′ and B′ respectively.

Join OA, OB, OC, and let OH be parallel to the plane of the circle ABC. Then $CH = \lambda$ and $AA' = BB' = CH = \lambda$.

Draw the tangents to the sphere at ABC. These tangents lie on the curved surface of a cone whose apex P, is such that O′P passes through the centre O′ of the circle ABC which is the base of the cone. The curved surface PAB represents the plane of the traverse and it is very nearly flat.

Then angle AO′B = angle A′OB′ being the angle between the meridians A and B also angle OAP = angle OBP = angle OCP a right angle; so that angles APO = angle BPO = angle CPO = complement of angle AOP = complement of angle BOP = complement of angle COP = angle AOA′ = angle BOB′ = angle COH = λ.

$$\therefore \text{PA} = \text{PB} = \text{PC} = r \cot \lambda.$$

Now the angle between the meridians of A and B is the "convergency" of the meridian of B. This angle is measured by the arc A′B′ on the equator divided by the earth's radius or by the arc AB divided by its radius on the parallel of λ.

But if the cone be flattened out it will be a sector whose radius = PA = PB = PC and whose arc will be the circle ABC.

$$\begin{aligned}\therefore \text{arc AB} &= \text{Cir. measure of angle AO′B} \times \text{PA}.\\ &= \text{Cir. measure of angle A′OB′} \times \text{PA}.\\ &= \text{Cir. measure of convergency} \times r \cot \lambda.\end{aligned}$$

But for distances not exceeding 8 or 10 miles, the departure (d) of B from A may, with great approximation, be taken for the arc AB.

$$\therefore d = \text{Cir. measure of convergency} \times r \cot \lambda.$$

$$\therefore \text{Cir. measure of convergency} = \frac{d \tan\lambda}{r}.$$

Let M = No. of minutes in angle of convergency of B's meridian.

$$\therefore \text{Circular measure of convergency} = \text{M} \sin 1',$$

$$\therefore \text{M} \sin 1' = \frac{d \tan \lambda}{r} \quad \dots \quad \dots (1)$$

or $\text{M} = d \tan \lambda \times \frac{\text{cosec } 1'}{r} = d \tan \lambda \times \text{K}$ (since $\frac{\text{cosec } 1'}{r}$ is constant).

$$\therefore \log \text{M} = \log d + \tan \lambda + \log \text{K}.$$

If d is expressed in miles $r = 3{,}958 \cdot 06$ (mean radius of earth),

and $\log \text{K} = \log \frac{(\text{cosec } 1')}{3{,}958 \cdot 06} = \log \text{cosec } 1' - \log 3{,}958 \cdot 06.$

$$= 3 \cdot 536{,}2739 - 3 \cdot 597{,}4824 = \bar{1} \cdot 9388.$$

If d is expressed in feet.

$$\log \text{K} = \log \left(\frac{\text{cosec } 1'}{3958 \cdot 06 \times 5280}\right) = \log \left(\frac{\text{cosec } 1'}{3958 \cdot 06}\right) - \log 5280.$$

$$= \bar{1} \cdot 9388 - 3 \cdot 7226 = \bar{4} \cdot 2162.$$

In this way it may be shown that log K = $\bar{2} \cdot 2161$, $\bar{4} \cdot 2161$, $\bar{2} \cdot 0357$ or $\bar{1} \cdot 9388$ according as d is expressed in 100 ft. chains, in feet, in Gunter's chains or in miles.

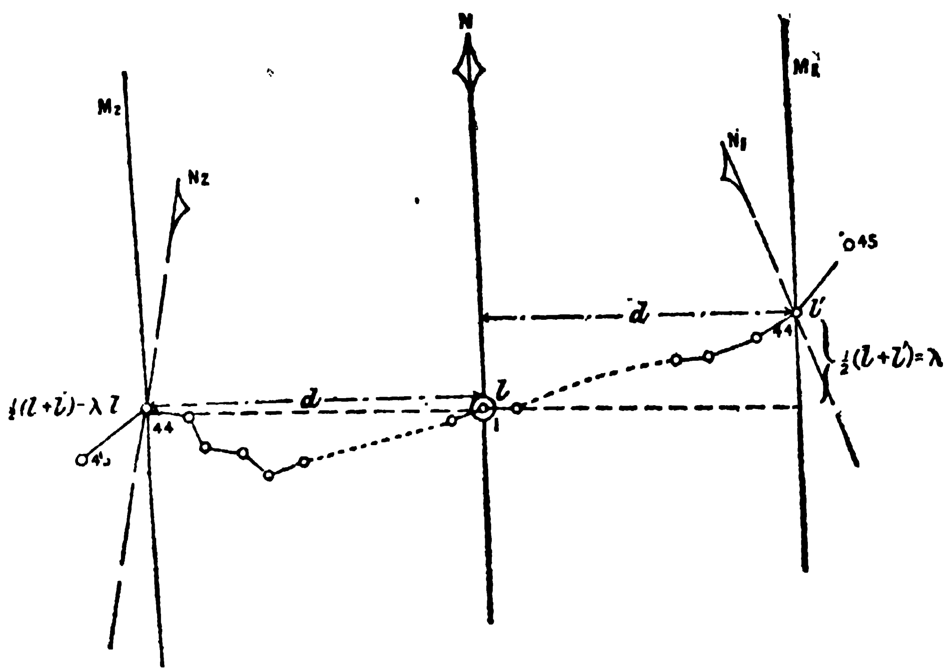
Example.—What is the convergency for 1 mile in latitude 30° N or very nearly the latitude of Roorkee ?

Miles.	Feet.	100′ chains.	66″ chains.
$\bar{1}$·9388	$\bar{4}$·2161	2·2161	$\bar{2}$·0357 log K.
$\bar{1}$·7614	$\bar{1}$·7614	1·7614	$\bar{1}$·7614 log tan 30°
0·0000	3·7226	1·7226	1·9031 log departure.
$\bar{1}$·7002	$\bar{1}$·7001	$\bar{1}$·7001	$\bar{1}$·7002 log convergency.
·5 mins.	·5 mins.	·5 mins.	·5 mins convergency.

that is in latitude 30° N the convergency per mile is equal to 30 secs. or ½ minute.

When the points between which the convergency is required are in different latitudes then the mean of the sum of the latitudes must be substituted for λ or $\lambda =$ ′ $l+l'$) in the above formula.

Fig 61 (*a*).



The application of convergency correction to a traverse.—Traverses are computed on directions and measurements and the directions are in terms of an initial direction which is usually an azimuth obtained from an astronomical observation that is in terms of true N. It therefore stands to reason that at a station E or W of the initial meridian, if an azimuth is observed, the directions, as carried forward on the traverse which are bearings, and in terms of the initial meridian, will not agree with the azimuth taken at a certain station by the amount of the convergence of the two meridians and therefore the azimuth must be reduced to a bearing by adding or subtracting the convergency angle in order to check the angular

work of the traverse. In figure 61(a) it is supposed that 1 is the initial or origin point and that a traverse has been carried to station 44 in an easterly as well as westerly direction and that an azimuth was observed at these stations to check the angular work. M_2 44 and M_1 44 are supposed to be parallel to the initial meridian through station 1 the origin. The azimuthal directions at stations 44 will be N_2 44 and N_1 44 and the angle N_2 44. M_2 and angle M_1 44 N_1 will represent convergency.

Now the azimuth of station 45 from station 44 is in one case N_2 ·44·45 and in the other case N_1 ·44·45 and if C = angle of convergency then the bearing of 45 from 44 will be N_2 44·45 + C when the station 44 is West of the origin and N_1 44·45 — C when the station 44 is East of the origin of survey. Therefore convergency is to be added to the **azimuth** or subtracted from the azimuth of a station in order to obtain **bearing** according as the station is West or East of the origin or initial meridian.

In the traverse form at the origin the initial azimuth in column 3 is entered as the bearing and opposite station 44 the bearing of 44 to 45 which is equal to azimuth $\pm$ C according as station is $\frac{W}{E}$ of origin. The angles in column 2 are then added down to and including station 44 and the total in whole degrees minutes and seconds should agree with the difference of the starting and closing bearing if not a correction + or — is applied and the bearings run down and closed without error. This correction is the angular error in the traverse and hence azimuths with convergency applied is an angular check.

120. The following points should be remembered in traversing with the theodolite—

(a) Much more depends on the accuracy of the chaining than on the angular work. The chaining to a flag 1,000 feet distant may be + 1 foot in error but an error in reading (not a mistake in reading) would scarcely show any displacement of the flag.

(b) The instrument and flags should be properly centred over the station marks, an error of an inch in displacement of either at a distance of 100 feet will produce an angular error of about 3 mins. The angular error increases as the distance decreases and vice versa.

(c) The permissible error in ordinary traverse chaining may be taken as 1 in 1000 but in city surveying with a steel band or tape the error should not be greater than $\frac{1}{5000}$.

(*d*) The chain should be tested against a steel band or an auxiliary chain before and after work and if possible once in the middle of the day and the correction applied to all measures accordingly and the corrected value should appear in red ink. Chains stretch, especially new ones, so that the recorded measurements are less than the real.

(*e*) When chaining, the chain should be well shaken as the alignment is being adjusted. The reason for this has been explained already.

(*f*) A chain should be examined for correctness in the intermediate lengths. It might so happen that the chain registers 30 feet or 30 links quite correctly and be a foot or link out at 15 so that a length of 115 feet or links will be possibly a foot wrong. It is for this reason that some surveyors use a reliable tape to measure the final measure which is part of a chain.

(*g*) Chainmen should at every chain length exert the same pull and align themselves automatically between the flags. The last arrow pitched, before the station is reached, should be left till the final measure is examined, checked and entered and also the number of arrows with chainmen. Some chains are fitted with a spring balance and for accurate work the pull can be regulated to counteract any discrepancy in the chain or tape.

(*h*) The centering of the theodolite over each peg cannot be too carefully done especially when menials are present as it impresses them with the accuracy of requirements necessary for good results. A theodolite fitted with a traversing head saves a good deal of time.

(*i*) The rods or flags should be observed to as low down as possible to obviate the error due to non perpendicularity.

(*j*) The field record should be in ink and all erasures should be cut out in ink, initialled and dated. The field book should contain an index plan and an index to pages so that data sought can be found with little or no trouble. The field book with its record must be so kept that any computer is able to understand the entries and is able without further reference to set up and compute the traverse.

(*k*) Arrows should be pitched vertically and the chain swung aside so that the chain in its drag will not pull them out of position

Arrows in long grass should have pieces of cloth run through the loops to catch the eye. To define the position of arrows on pavements a chalk line with a fine pencil line in the middle is the best mark.

(*l*) On the final part chain measurement it should be a rule that the chain is dragged past the station and aligned on the back station. The chain measure will then be given as so many chains and so many links or feet.

If the forward end of the chain reached the mark and the chainman held the chain against the last arrow it is quite possible, and in fact so often happens, and it is noted here as a precaution, that he will call say 74 feet instead of 26 feet. The same mistake may happen with the steel tape by holding the 100 feet at the station mark and obtaining the tally at the arrow from the chainman.

(*m*) Offsets should be taken by means of a cross head or optical square and metallic tape. The measuring chains should not be used for offset work.

(*n*) Measurements must be done "pari passu" with the angular work.

(*o*) As levelment does not effect horizontal angles much and a slight deviation of the bubble little or nothing, the bubble should *never* be corrected during observations (see paragraph 70.)

The squad required for ordinary traversing with two chains going will be as follows. Chainmen 4, Flagmen 2, Menials for instruments and umbrella 2 and possibly an "axeman" or line clearer. Total 8 as a minimum and 9 as a maximum.

CITY SURVEYING.

121. City surveying demands from the engineer and surveyor a higher order in accuracy than that of farms or property in an agricultural or depopulated area. The accuracy may be said to increase in proportion to the value of property bearing in mind also that, in well established ports and commercial centres, ground rents and building sites may yearly increase in value and thus in some cities and also in certain quarters of some cities the highest class of surveying as regards accuracy is an absolute necessity. Probably its main object is to avoid litigation and thus the survey map becomes the supreme court of settlement.

However the aim in accuracy should not be so much *great* precision as the *required* precision under the circumstances and on this the cost of the survey should be worked out, the municipality or governing body on the one hand tabulating a list of detail it requires shown and the surveyor then selecting the scale or scales, on which the city area is to be surveyed. If the municipality decides the scale, amount of detail &c., the

surveyor is left with the question of accuracy to which he must work to satisfy the requirements laid down. Again the size of the scale will decide whether the actual plot is to be the legal map from which all measurements are to be taken or whether measurements are to be printed along the lines of a conventional plot. If the scale is a large one, say 20 feet to the inch it would be folly to suppose such a map was intended as a guide map for printed measurements, rather it should be a map plotted accurately to all measurements and from which areas and detail can be calculated.

In a city survey the framework must first be considered and that framework will in all probability be a theodolite traverse in preference to triangulation. Triangulation would not only be expensive but possible only from the tops of houses and the points thus fixed would have to be transferred to the ground level.

122. As theodolite traverses would all be closed traverses there necessarily arises the question of the required precision and that required precision will have been attained when on the closing error of a traverse being dispersed no station, according to scale, will contain a plottable error. On scales of 25 to 50 feet to the inch values to $\frac{1}{10}$th part of a foot may be considered as plottable or at any rate values to this accuracy or a slightly greater accuracy should be aimed at in the computation, in which case measurements, latitudes and departures, should be taken to the 2nd place of decimals of a foot. Tape measures of lengths are therefore required to the part of an inch.

The error of closure should be perhaps within $\frac{1}{10{,}000}$ where error of closure $E = \frac{\sqrt{(\text{error in latitude})^2 + (\text{error in departure})^2}}{\text{perimetre}}$.

For example in a 10,000 feet perimetre which is a little less than two miles if a traverse is found to be ·6 feet error in latitude and ·8 feet error in departure we get from the formula $E = \frac{\sqrt{(\cdot 6)^2 + (\cdot 8)^2}}{10{,}000} = \frac{1}{10{,}000}$

The accuracy of closure of a traverse of this description to between $\frac{1}{2}$ and $\frac{2}{3}$ of a foot seems reasonable to expect and when such an error is dispersed or distributed through 50 stations of an average distance of 200 feet apart, the plottable error might be considered *nil.*

It has been already shown that some errors are accumulative and some compensating and therefore a few important main lines common to main traverse circuits may be required to be accurate to $\frac{1}{17{,}000}$.

It must be remembered that the areas will be calculated from the traverses so the distribution of error in precise work should be carefully done and as follows :—

The error per side in latitude $= \frac{\text{total error in lat.}}{\text{perimetre}} \times$ length of the side, and the error per side in departure $= \frac{\text{total error in departure}}{\text{perimetre}} \times$ length of side

The slide rule will be found a quick and accurate method for the above.

123. As regards the angular work it will be found that a transit theodolite with traversing head (sometimes known as railway pattern stand) reading to 20 secs. with 3 repeat readings will suffice, but it is doubtful whether a 6 or 8 inch micrometre reading to 10 secs. and estimation to 2 secs. with one extra check angle would not be a more suitable instrument when traffic is liable to vitiate several repeat readings.

The angular correction to the traverse should be based on the system of closure of angles of a polygon and the excess or defect distributed equally. If this is admitted then there arises the question of azimuths to control the angular error and as both azimuths and the sum of the interior angles of the polygon must rule the angular correction, a judicious selection of the azimuthal stations must be made, and the angular correction through several blocks distributed before any balancing can be done.

The probable angular error per station would be the total error divided by the square root of the number of stations. There being two conditions to satisfy it must arise that many azimuth stations would tend to confuse and complicate matters.

124. There is no need to have more than one origin for ordinary sized cities. True, the co-ordinates may seem to be unwieldy, running into thousands, but the full set of figures need only appear once on the top of each page and at each change in the thousands.

The city might be supposed to be divided up into main traverse blocks, wards or any such municipal administrative areas (perhaps it would be most convenient for compilation to adhere to some municipal rather than survey units), each block being roughly about ½ square mile. The common line between blocks of main traverses should be traversed twice and in opposite directions and the mean accepted for each block so that the stations along the common line will agree. No error can, therefore, be distributed unless it is distributed to each block on the common line. It will thus be seen that the traverse main network for the whole should be set up and balanced before these blocks can be divided up by sub-circuits into smaller areas.

125. The main traverses should have permanently marked stations, known as monuments, the positions of which should be properly selected and fixed also by accurate measurements to adjacent permanent marks. The main traverses will be run in the most convenient way and along lines of least resistance and not with the sole view of aiding detail work. The distance between main traverse stations should be as great as possible, as then compensating errors in tape lengths will permit of the measure being nearer the truth.

126. Sub-circuits and tie lines will be run from these main traverses up all streets and possibly alleys and by-lanes and the stations of these sub-circuits should, considering the scale, be so placed that on plotting, at least five or six will appear on the sheet of paper used for detail work. The detail work may be carried out by tape and offset methods and the work to be plotted direct on the table as it proceeds, or by telemeter methods with the Tacheometric planetable. With the former the surveyor must be careful to work from the greater to the less and not vice versa, that is, in a given block it would be correct to divide up the block by supplementary tie lines and to fill up the resulting small blocks after the tie lines close and are checked. It would be incorrect to start detail work on the whole block in one corner and continue filling up the block as then the error will be accumulative and an impossible one to disperse.

127. A standard at mean temperature measuring 100 feet should be set up at the city head quarters, such as a town hall or municipal offices, and all steel tapes and other classes of tapes used should be standardised to this measure and in the future in case of disputes arising as to ownership etc., this standard should be referred to.

128. City levelling, should be levelling of precision and level values should be given where the city authorities are likely to require them. The sites selected for bench marks should be of a permanent character.

129. Any point needing settlement should be submitted to the proper authorities to adjudicate on and the map drawn accordingly.

130. Street lamps, hydrants, manholes, subways etc., should be accurately shown on the map in conventional colours ; those below or above ground level should not be confused with those at ground level.

131. The demarcation of the drainage system for houses and streets and the outlets for sullage water should carefully be attended to. The widths of streets and pavements and up to which limit they are paved or otherwise should be given. Property belonging to harbour, railway and other large landowners, should be measured along their boundaries and where insufficient marks exist or where the boundary is doubtful these facts

should be noted and settled. The corners of all street blocks near monuments should be measured to and recorded in a proper manner, and if necessary, the measures should be entered on the map. When the map has once been plotted and examined the field books should be considered of no further value. Either the plot of the map or the added measures must be considered sufficient and no satisfaction can be had from field books which contain offset information and not direct measures or diagonals. All measures printed on the map must be direct measures and not measures deduced from offsets.

132. The geographical situation of detail in a city survey is of no practical use whatever, so that traverse coordinates need not necessarily be joined on to adjacent geodetic data. An index map on a small scale can easily be compiled as the mapping proceeds and the reduced plan can be made to fit on to two or three data common to both.

132. City surveying is mostly carried on at night or when traffic more or less ceases. The planetable methods, called in Part II, Tacheometric surveying, is eminently adapted for city work as stadia observations can be made and distances obtained without fear of interference by traffic.

133. What has been written is applicable to city surveys to be used by the engineer for construction, improvement etc. The Ordnance Survey of England does not undertake to settle ownership of property and for general use a scale of $\frac{1}{500}$ has been found large enough for all municipal purposes. Any survey on a scale of 20 feet to the inch becomes a working plan. In India the Government requires railway location work on a scale of 400 feet to an inch, and if so, town planning and city improvement must suggest a larger scale and possibly 200 feet to the inch would be required; bazaars and crowded areas have been surveyed on scale of 24 and 36 inches to the mile.

134. The plan drawing should not contain shade lines for buildings as confusion arises as to whether the inner or outer edge of the shade line is the measured limit.

CHAPTER VI.

LEVELLING.

135. Some writers object to levelling being considered a branch of surveying as it is argued that surveying deals solely with the plan of the earth's surface whereas levelling has to do with the sectional portion of it. From an engineering point of view levelling is of first importance and as this book has been written for the engineer rather than the reconnaissance or military surveyor it has been incorporated as a branch of surveying.

136. The object of levelling is to find, (1) how much one point on the earth's surface is higher or lower than another given point; (2) to fix a point or points of a certain height above or below or on a level of the certain given point.

137. **Datum.**—All elevations are referred to some imaginary surface which is assumed to be of zero level and the mean surface level of the sea is the most convenient datum to assume. This is not an invariable rule as if the relative heights are only required of a certain small detached area some other conveniently assumed datum may be accepted, the assumed datum surface in this case should always be lower than any possible elevation found in the area for convenience of the plot. The *datum* of the English Ordnance Survey is the mean sea level (M. S. L.) at Liverpool and of the Survey of India the M. S. L. at Karachi.*

138. **Bench marks** are points of reference whose heights or elevations above the assumed datum are found and known. These points should be carefully selected and distributed according to the needs of the country. In a city bench marks would be at closer intervals than in the country. Standard bench marks are usually obtained by precise levelling under the ægis of a Government and such values are found along trunk roads and railways where the going is easy, the grades flatter and clear sights are obtainable. Some authorities prefer to have their B. Ms. engraved and fixed. This system of marking is not always safe in a semicivilised country where a brass disc or a stout nail is of some local value and hence the ultimate destruction of such marks. It is best under such circumstances

* It is generally understood to be the M S. L. at Karachi but actually the reduction of the Indian levels connect the level net with M. S. L. at 9 stations, Karachi being one.

to select an unplastered slab which is also well protected from traffic † and to carefully describe its position and note its measurements relative to near and well recognised objects. Bench marks need not necessarily be at or near ground level, a cornice or other mark can be selected and measured to by means of the staff held upside down.

139. **Theory of Levelling.**—When a level has been set up and the line of sight made horizontal, it is required to find how much above a certain point in the plane of sight this object is. Except for this calculation the height of the plane of sight, usually known as the height of instrument or H.I. has nothing whatever to do with levelling and hence the form of the field book advocated in which the height of instrument has been ignored.

To obtain the height of the plane of sight and then to transfer its value to another point on the earth's surface, some other instrument besides the level is necessary. This instrument is known as the *levelling staff* (or self reading rod) and is a piece of well seasoned wood painted and graduated to decimals of a foot or metre (see para. 87). The staff held on the point the reduced level of which is known, is the *back sight*, and the staff on the point, the value of which is required, is the *foresight*. Owing to errors in graduation etc., it is customary to use one staff only and the use of two staves is not advised unless they have both been thoroughly tested to give the same readings at different parts of the staves each to each. The coefficient of expansion in staves used in precise levelling for different temperatures should be known and recorded.

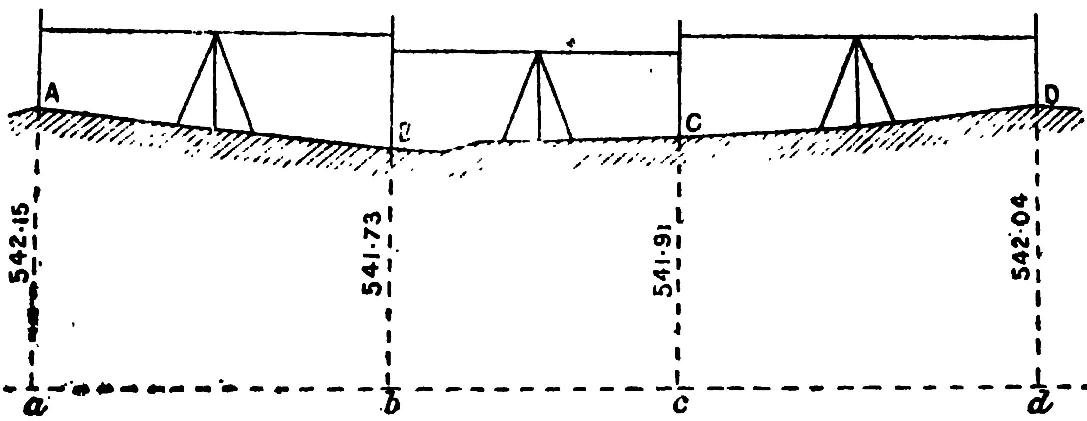
140. **A level surface** is not a horizontal surface but a curved surface which is at right angles to the plumb line at any point in that surface, so that a level line is not a straight line but a curved line and would conform exactly to the earth's surface were that surface a perfectly regular one. Compare the surface of a large still lake which is a level surface and yet not a horizontal one. The line of sight is a horizontal line and is a tangent to the level surface which passes through the observer's eye and hence a correction for curvature would have been necessary if it were not for the short lengths taken between staves when curvature has no effect (compare reciprocal levelling) and also as the instrument is invariably placed midway between the staves when the allowance for curvature and also refraction is cancelled and eliminated.

† The recently published volume on levelling of precision issued by the [illegible] of India on page 64 points out that Bench Marks along railways and roads are not al[illegible] satisfactory owing to the continual vibration set up by traffic and although the le[illegible] might work along the railway or road, bench marks are set up at a distance.

141. The following explanation will show how levelling is performed and with reference to the college pattern form (end of para. 145) substitute for A B C D stations 9, 10, 11 and 12 and compare values.

Suppose we want to know the ups and downs of a line along which a road on canal is to be run. We should always start from some permanent

Fig. 62.



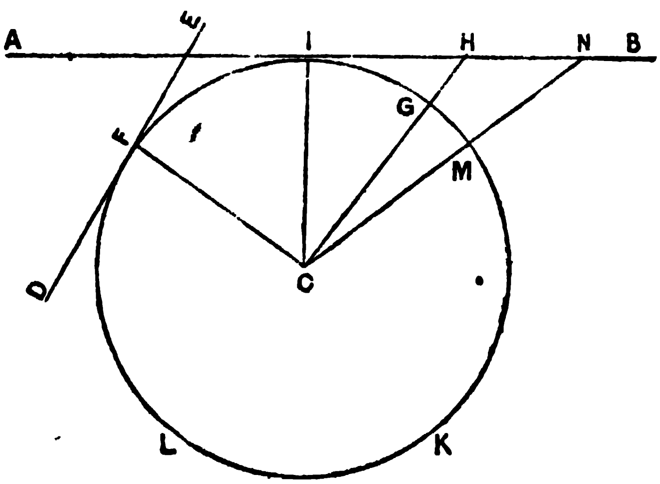
point, such as the edge of a well or step of a building, whose height and position will not vary, and we set up the instrument between A and B, and make the telescope truly level; then putting the staves on A and B, fig. 62 say, that when we look at them through the telescope, the hair cuts them at 3·90 and 4·32 respectively, then we know at once that point B is 4·32 −3·90 or 0·42 below A. We then remove the level to between B and C, and find that the two staves placed on these two points read 4·90 and 4·72, thus showing that C is 0·18 above B, or in consequence 4·22 – 0·24 below A, and so on we can move to between C and D. &c., and find the levels of any points with reference to A. If also we know the height of A, or any of the points above the mean sea level at Karachi, which is the datum to which all levels should be reduced, we can reduce the levels of all these points to that. Thus say A is known to be 542·15 above the mean sea level. This is called its *reduced level*, then that of B will be 542·15—0·42, or 541·73. Similiarly that of C will be 541·73+0·18, or 541·91.

If now a line be drawn to represent the M. S. L. at Karachi, as *a, b, c,* and the distance *ab*, *bc*, measured at AB, BC, &c., mark off the vertical off-sets *a*A = 542·15, *b*B = 541·73, &c., can be laid off, and the line A, B, C, D, plotted, which will be a correct vertical section of the line of road, &c., required, if the staves have been put up as they should be at the points where the slopes change, or the corners in fact.

This is really the whole business. *a, b, c, d*, is the datum line, a permanent point such as A, on the well, is called a bench-mark, and reduced level, the other term, has been explained.

142. **Curvature of the earth and refraction.**—This has an effect on the observations so must be considered. In the figure if the instrument is supposed set up at I, and staves at unequal distances from it, as G and M, then the heights read off on the staves will be the unequal one GH and NM, which, as the points G and M are truly level with I, will give an error.

Fig. 63.



This error is, however, modified to a certain extent by the optical deception arising from the refraction from the air which acts in the opposite direction.

A Table, No. VII, of the combined error is given at the end of the book, and as the greatest distance at which the staff can be read by the best levels is only about 500′, it will be observed that the error ·00598 is very small, and may be safely neglected in all but the most exact and scientific observations.

The extreme case, moreover, in which the error is ·00598, a measure in itself barely readable on the staff, only occurs in the very unusual condition when one staff has to be read close to the instrument and the other at 500 feet off. Had one been at 400 and the other at 500, the error would only have been the difference of the error at both readings, *i.e.*, ·00598—·00383 or ·00215, and if the distances of the two staves from the instrument are even the errors of course cancel. The errors, caused by the instrument not being in perfect order, are much greater than those caused by curvature and refraction, but these also are eliminated by working with the instrument midway between the staves, as it is evident that even if the telescope points up or down instead of level, it makes the same error at both readings, which cancel and give a correct *difference* of level which is the result sought.

143. **The following are the different classes of levelling:—**

(1) *Precise levelling* for the establishment of bench marks (B. Ms.) over a large tract of country. Examples—Great Trignometrical-levelling in India, Ordnance levels in the United Kingdom, France etc., Geodetic levelling in the United States of America.

(2) *Check levelling* to find the difference of height between two points. This is also known as *differential* levelling.

(3) *Profile or longitudinal levelling* in which the object is to find the exact slope, trend or the section of the ground from which may be worked out the grades of a railway or the fall or slope of a canal.

(4) *Cross-section levelling* in which the object is to supply a further series of sections at right angles to the longitudinal levelling so as to determine the general cross slope of the ground or the bed of road, railway or canal and for the estimation of cutting and filling.*

(5) *Flying levels* for approximate elevations.

(6) *Reciprocal levelling* to obtain the difference of height between two points which are separated by a natural obstacle like a river where it is impossible to obtain an intermediate set up of instrument.

144. **Precise levelling.**—This treatise is designed more for the engineer than the geodetic surveyor and therefore no attempt will be made to describe this class of levelling as it is a special branch requiring special precautions and methods of error distribution. Some of the features of the corrections † applied are as follows—for deflection of plumb line due to the attraction of mass—effect of sun on the spirit bubble—personal error accumulation in one direction so that sections are levelled in an inward and outward direction—correction for bubble divisions etc. A word might be said concerning the limit of error or the accuracy to aim at in first class levelling. If error in feet$=$Constant $\sqrt{\text{distance in miles}}$ is accepted as a working formula then for precise levelling $C=0{\cdot}02$ is considered a fair average constant so that the permissable error in 9 miles$=0{\cdot}02\sqrt{9}=0{\cdot}02\times3={\cdot}06$ feet; for 100 miles it would be ${\cdot}2$ of a foot etc. In ordinary levelling 5 times this amount is permissable or C might be taken to equal $0{\cdot}1$ ‡. As instruments are perfected it is quite possible that this constant will be too large.

Check longitudinal and cross section levelling are fully explained in the field book and the student, engineer or surveyor should have no difficulty whatsoever in following out the procedure advocated and recording them in a neat and proper manner.

* In undulating ground two ten foot staves clamped together making in all 19 feet will expedite work considerably.

† It would be perhaps more correct to say that the system of observing has been designed to cancel suspected causes of error. The causation of such error is still under investigation.

‡ If a leveller levels back over his line as a check the distance will be half and not the whole for finding the error as certain errors are compensating.

145 (*a*) **Levelling Field-Books.**— Many forms of field-books are in use, and an experienced leveller will generally prefer his own. The two forms in most general use in these Provinces are—1*st*, the pattern adopted by the late Col. Dyas, R.E, first tried on the Sutlej Canal Project, and now adopted generally for the Irrigation department; and 2*nd*, an improvement on the English pattern. A specimen of both is here given, and also the latest pattern as now used at the Thomason College. It is to be noted that the numbers of the stations refer to the positions of the staves and not to those of the instrument.

(*a*) CANAL PATTERN.

No. of back station.	BACK. Reading.	BACK. Bearing.	Distance from instrument toeach station.	FORE. Bearing.	FORE. Reading.	Difference. Rise.	Difference. Fall.	Reduced level of back station.
1	4·56	7°	300	187°	5·34		0 75	451·42 R. L. of G. T. S.
2	6·18	7°	300	187°	5·54	0·64		451·28
3								

(*a*) *Opposite page for Survey.*

2	268° Kunderpur, ⊙	⊙	95° 85' B. M. on plinth of mile-stone 3·48.
1½	324°	⊙	

Station 1½ is between 1 and 2, where the instrument is set up.

(*b*) ROORKEE PATTERN.

Back.	Intermediate.	Forward.	Distance.	Bearing.	Rise.	Fall.	Reduced Levels.	Remarks.
·56				187°			500·00	R. L. of starting point.
	5·34					0·78	499·22	Bench-mark No. 1 (G. T. S.).
·71		4·21	500	172°	1·13		500·35	
	4·80		800		2·41		502·76	Left bank of river.
	8·40		828			4·10	498·66	Highest flood mark, left bank.
	11·90					3·50	495·16	Level of water, Jany. 1st, 1868.
	8·50		1,006		3·40		498·56	Highest flood mark, right bank.
·03		2 65	1,064		5·85		504·41	Right bank, cross section No. 1.
	2·50		1,200		4·53		508·94	Small irrigation channel.
		3·42	1,400			0·92	508·02	
·30		10·28						Check on arithmetical work.
·28								
·02	Total rise R. L. 508·02.							

Both of these forms are good, though the latter is more generally useful.

The following form of levelling book is now frequently used by English surveyors, and was apparently first introduced by the American Engineers, The specimen given below comprises the same information as shown in the specimen above:—

Station.	Distance.	Staff reading.	Height of instrument.	Reduced levels.	Remarks.
1	0	4·56	504·36	500·00	Reduced level of starting point.
		5·34		499·22	Bench-mark No. 1 (G. T. S.).
2	500	4·21		500·35	
		6·71	507·06		
	800	4·30		502·76	Left bank of river.
	826	8·40		498·66	Highest flood mark, left bank.
		11·90		495·16	Level of water, 1st January 1868.
	1,006	8·50		498·56	Highest flood mark, right bank.
3	1,064	2·65		504·41	Right bank, cross section No. 1.
		7·03	511·44		
	1,200	2·50		508·94	Small irrigation channel.
	1,400	3·42		508·02	

In this form it will be noticed that all the staff readings are entered in one column; to get the height of the instrument it is only necessary to add the "back reading" to the last reduced level, and then the reduced levels of the several stations are obtained directly by subtracting each staff reading from the last entry in column "height of instrument."

The objection to the American form given is that there is no check of the arithmetical accuracy of the work, such as that obtained in the older form by adding up "back" and "forward" columns, and seeing that the difference of their sums agrees with the total rise or fall in the page as shown by the "reduced level."

(c) The pattern now adopted at the Roorkee College is given below, filled in to show the working, with a copy of the general directions which are printed with each book:—

NOTES.

1. Commence at the top line of the 1st page, entering the starting B.M. with its reduced level opposite it.

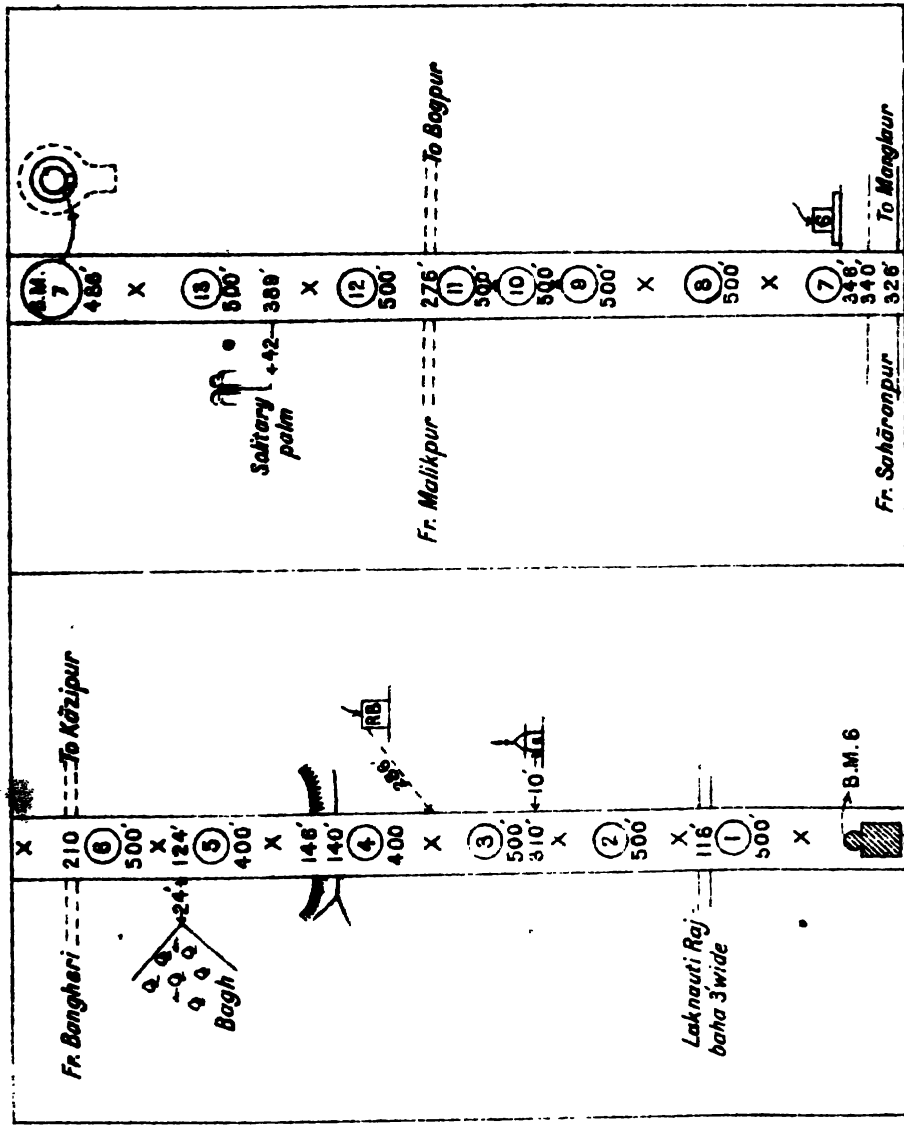
2. Always start with the true reduced level, *i.e.*, the height of the B.M. above mean sea level at Karachi. If you use an assumed datum your levels will be useless as a record.

3. Plate XIII shows a specimen of cross section or traverse section work, and Plate XII, a specimen of permanent line section.

4. A survey along the traverse should be made while levelling, and entered on the opposite page, distance being shown from peg to peg, not continuously; it is convenient to show the instrument station by an ×. For cross section work details should be drawn in hard clear lines, as far as measurements can be made conveniently with the 10-foot rod, or

PLATE XI.

Field Book (Left hand page facing above record of Levels)

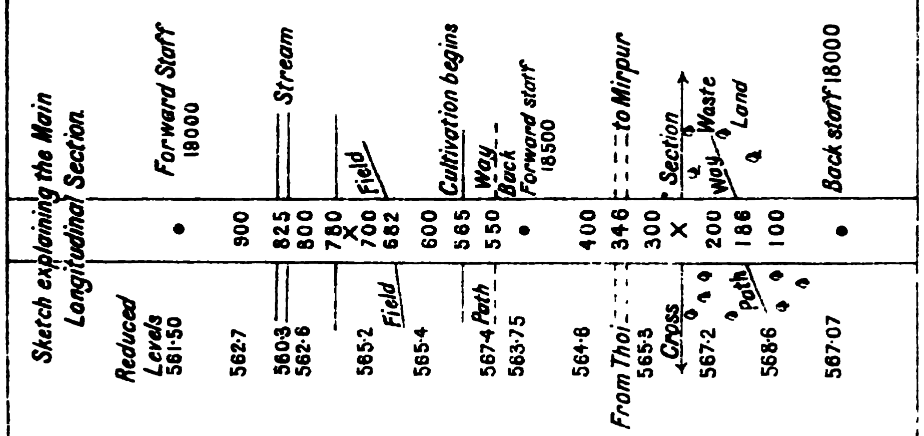


Levels from B.M.(6) near Nagla to B.M.(7) on well at Baheri, 3/4/10

No.	Distance	Bearings Back	Bearings Fore	Readings Back	Readings Int.	Readings Fore	Diff. +	Diff. −	Reduced Levels.	Remarks
	Feet	Degrees	Degrees							
B.M.(6)	500	30	210	5·35		6·10		·75	543·30	Top centre of trijunction pillar villages Nagla, Baheri and Shāhgarh
1	500	30	210	5·40		4·93	·47		542·55	
2	500	38½	218½	4·82		5·27		·45	543·02	
3	400	38	218	3·18		4·50		1·32	542·57	
B.M	286	118	. .	. . .	2·14	. . .	1·14	. . .	543·61	On top of road boundary
4	400	17	197	4·72		4·60	·12		541·25	
5	500	36¼	216½	5·14		5·14			541·37	
6	346	40	220	6·05		5·00	1·05		541·37	On top of milestone 6 Manglaur-Sahāranpur Road
7	500	43	223	4·32		4·85		·53	542·42	
8	500	43	223	5·15		4·89	·26		541·89	
9	500	43	223	3·90		4·32		·42	542·15	
10	500	48½	228½	4·80		4·72	·18		541·73	
11	500	30	210	4·83		4·70	·13		541·91	
12	500	34	214	5·16		4·95	·21		542·04	
13	486	76¼	257	4·93		2·16	2·77		542·25	
B.M(7)				67·85		66·13	5·19	3·47	545·02	On top of parapet of well in Lal Singh's Garden Baheri (Water-Surface 18 feet below mark)
				66·13			3·47			
				1·72			1·72			

Field Book (Left hand page facing above record of Levels)

Note – The positions of staves and reduced levels are given here to make the record quite clear; they will not be entered in the Field-book which will be kept in the ordinary way.

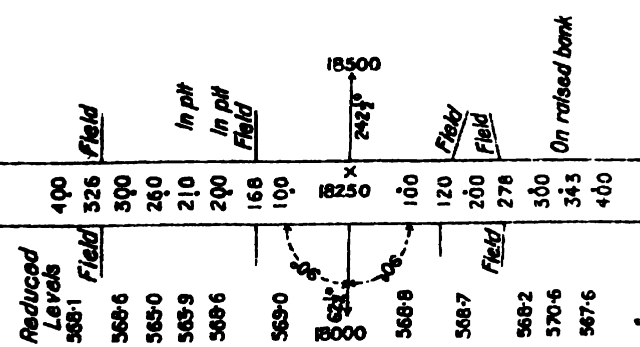


(d) Main Line Longitudinal Section 18000 to —————— 5/2/11

No.	Distance	BEARINGS.		READINGS			DIFF.		Reduced Levels.	Remarks.
		Back.	Fore.	Back.	Int	Fore	+	—		
Feet.	Feet.	Degrees	Degrees							
18000		62½	242½	4·56		7·88		3·32	567·07	
	100				3·1		1·5		568·6	
	200				4·5		·1		567·2	
	300				6·4			1·8	565·3	
	400				7·1			2·5	564·6	
	500	62½	242½	5·67		7·92		2·25	563·75	
	550				2·1		3·6		567·4	On raised path.
	600				4·1		1·6		565·4	
	700				4·3		1·4		565·2	
	800				6·9			1·2	562·6	
	825				9·2			3·5	560·3	In Small stream 2 Feet wide
	900				6·8			1·1	562·7	
19000		62½	242½	4·61		3·39			561·50	
	100				4·7			·1	561·4	
	200				3·9		·7		563·2	
					etc.,	etc.				

Field Book (Left hand page facing above record of Levels)

Note–The positions of staves and reduced levels are given here to make the record quite clear; they will not be entered in the Field-book which will be kept in the ordinary way.



(e) Cross section taken at chainage 18250 on the Main Line Longitudinal Section—52ft

No.	Distance	BEARINGS		READINGS.			DIFF.		Reduced Levels.	Remarks.
		Back.	Fore.	Back.	Int.	Fore.	+	—		
18000		$62\frac{1}{2}$		4·56		7·88		3·32	567·07	
	100		$152\frac{1}{2}$		2·7		1·9		569·0	
	200		$152\frac{1}{2}$		3·1		1·5		568·6	
	210		$152\frac{1}{2}$		7·8			3·2	563·9	In pit
	260		$152\frac{1}{2}$		6·7			2·1	565·0	In pit
	300		$152\frac{1}{2}$		3·1		1·5		568·6	
	400		$152\frac{1}{2}$		3·6		1·0		568·1	
	100		$332\frac{1}{2}$		2·9		1·7		568·8	
	200		$332\frac{1}{2}$		3·0		1·6		568·7	
	300		$332\frac{1}{2}$		3·5		1·1		568·2	
	343		$332\frac{1}{2}$		1·1		3·5		570·6	On raised bank
	400		$332\frac{1}{2}$		4·1		·5		567·6	
18500									563·75	

These Cross Section records should appear in a separate book. The above is an example of a cross section for railway work where the limit is usually 400 Feet on each side of the proposed alignment

(f) Showing method with Stadia distances

No.	Distance	BEARINGS.		READINGS.			DIFF.		Reduced Levels	Remarks
		Back.	Fore.	Back.	Int.	Fore.	+	—		
B. M.	189 324	$195\frac{1}{2}°$	$299\frac{1}{2}$	9·91		5·07	4·84		1002·08	*On Furlong post*
	181	$191\frac{1}{2}°$			10·58			0·67	1001·41	*On Curb stone*
	76	96°			6·40		3·51		1005·59	*On Water pipe*
1	363 426	$113\frac{1}{2}°$	296°	5·92		5·20	0·72		1006·92	
2	.	.	.	.	E & C	.	.	.	1007·64	
				15·83		10·27	5·56	0·00		
				10·27			0·00			
				5·56	*Proof*		5·56			

by compass bearings: important features lying beyond this range should only be sketched or dotted. The permanent line survey should be accurate, but only extend to the boundaries of the land to be permanently taken up.

5. Bench-marks should be carefully sketched and described, not marked: when read the level should *always* be midway between the B.M. and the reference peg. It is advisable, as a general rule, to divert the main line to the B.M. and then back to the original alignment, so as to record the exact position as well as the level of the B.M.

6. Intermediates of minor importance in cross section work may be read from the instrument station at uneven distances, and should be recorded with reference to the reading on a line peg as shown in the example.

7. When pegs are situated on local depressions the circumstances should be noted, and if necessary intermediates read to show the level of the natural ground surface.

8 Always end the day's work on a B.M., or a large square peg firmly driven in a situation easily described and found.

9. Never finally record a line of unchecked levels, however short or unimportant; note the check on the record. Long lines, where reliable B.M.s are not available, can be checked by running two simultaneous lines of levels on the same pegs, the instrument being twice set up and a double set of staff men employed.

10. It is good practice to take out rises and falls and check the work of each page in the field All pages should be headed, dated and signed. At the close of each day's work the *Reduced Levels* should be inked in, and the levels and survey plotted. The recording in the field *must* be done in ink.

11. Place the instrument always midway between the staves or at the apex of an isosceles triangle. Intermediates to fix the reduced level of a new permanent mark should only be resorted to if the instrument is in perfect adjustment.

12. If mistakes are made in the record they should be neatly crossed out and the correct figures entered above, initialled and dated. A knife or rubber should never be used for erasure or one figure corrected into another.

13. Each field book must be paged and a complete index of the work, with cross references, where necessary, made out at the commencement of the book.

(*g*) The following points should be noticed:—

(1) The back and fore reading are placed on the same line and the difference between them also on the same line.

(2) The reduced level appears on the same line as the station for which it is intended——Example, station 13 RL=542·25.

(3) The distance column denotes the distance between the back and the fore staff. Example, station 13 line, 4·93 is the back reading to station 13 and 2·16 is the fore reading to B. M. (7) and 486 feet is the distance between station 13 and B.M. (7) or 243 feet from station 13 to instrument and 243 feet from instrument to B M. (7).

(4) For the same reason the bearing of station 13 is 76¼° and the bearing to B.M. (7) is 257°.

Some authors prefer putting the forward reading on the line below the back reading and so forth, others prefer to have a column for height of instrument, others again one form for check levels and another form for

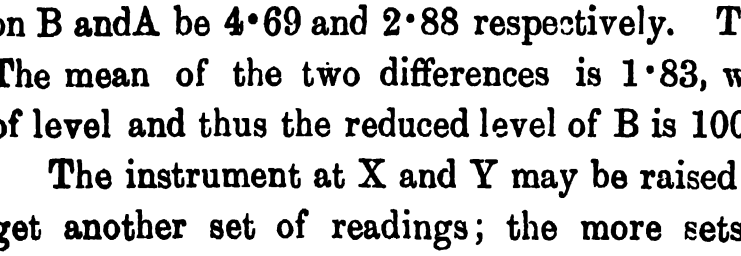
longitudinal and cross section work, but most of these have their separate faults or lead to a certain amount of confusion. The form herein given contains everything necessary and was set up originally by a very experienced engineer who himself has written a standard work on irrigation and only a few minor alterations have been made and embodied in the present form after consultation with experienced levellers and engineers.

146. **Flying Levels.**—These are run for approximate values only: longer distances intervene between instrument and staff and often readings only to the first place of decimals are made. Thus the work is rapid and hence the nomenclature.

147. **Reciprocal Levelling.**—Sometimes a wide river, marsh or other impediment has to be crossed and a detour is not feasible. The method of reciprocal levelling must be adopted to obtain correct values and for the elimination of curvature. When there is one instrument * and the accuracy of precise levelling is unnecessary the following is the method of transferring an elevation across a barrier of the nature above mentioned.

Set up the instrument at X say 30 feet from the staff A and so that XAB is a straight line; read the staff at A and at B. Let the reading A be 5·09 and B 6·9~~6~~4 and on the reduced level of A 1,000 feet. This gives 1·85 as one difference. With the instrument at Y 30 feet from B and ABY in a line let the readings on B and A be 4·69 and 2·88 respectively. This gives a difference of 1·81. The mean of the two differences is 1·83, which is the correct difference of level and thus the reduced level of B is 1000—1·83=998·17 feet.

Fig. 64.



The instrument at X and Y may be raised or lowered and relevelled to get another set of readings; the more sets of readings the greater the accuracy of the mean. It must be noted in the above that although curvature and error in instrument is eliminated refraction may not be, and it is for this reason that in precise work two instruments are used and readings are taken simultaneously and so that the instrumental errors † are cancelled; the instruments are also interchanged.

* With a single Kern level with five results a mean probable error of ±0·5 millimetre was obtained for a river ¼ mile wide.

† There is no guarantee that there is no instrumental error because instruments are usually adjusted over a distance of 300 to 400 feet as a maximum so that if the river is much wider than this it is quite impossible that there still remains a small error.

One instrument * is set up at X and the other at Y and the rods A and B will be placed to the front and to one side of X and Y so as to give clear sights. At a given signal X reads B and Y reads A, then X reads A and B reads Y and this may be continued and a number of sets taken. Then X and Y interchange and the same procedure is carried out. The mean difference by each observer and the mean of these differences is the true difference of level of the two staves.

148. **Field work.**—Set up the stand or tripod midway between two staves so that two of the legs are in a direction at right angles to the line between the staves that is one leg points either to the foresight or back-sight. Take the instrument out of its box very carefully and note before doing so the position in which it sits in the box and if necessary, make notes along the edges of the box so that it will invariably be replaced in one and the correct way. Set the instrument on the stand, screw it on, or clamp it in the slots of the tribach and examine it and the stand for any shake and remedy it before commencing work. With the eye focussing screw and with a piece of white paper in front of the object lens eliminate parallax first with the eye piece obtaining a sharp and clear view of the wires and then focussing the object glass on to the staff and noting that the wires do not move, that is that the image formed by the object glass is brought into the same plane as the wires. Adjust till perfect (see para. 60).

(1) Place one hand lightly on the telescope and one hand on the leg (pressed against the thigh) which points up and down the line. By means of this leg and a lateral motion to and fro bring the bubble to the centre of its run approx : the telescope being at right angles to the line Now bring the telescope into the line between the staves and with the leg still held in the hand raise it or lower it so that the bubble is brought into the centre approximately. Repeat if necessary. The object of pressing the leg of the stand against the thigh is to avoid jerks and snaps. These two movements should not take more than 10 seconds to do. The legs are now pressed well home and one or two turns of the footscrews should be sufficient to start the bubble moving.

(2) Turn the telescope in a direction at right angles to the line of sight when it will be over two foot screws. Twist these footscrews both equally inwards or both outwards and bring the bubble to the centre of its run. Now turn the telescope at right angles to its present direction when it will be in a line pointing to either the back or forward flag and bring the bubble to the centre of its run by the remaining footscrews if a four screw instrument, and by the other footscrew if a three screw instrument. Return

* The instruments should be preferably of the same power of telescope and value of bubble tube

to the first position, correct any deviation in the bubble and again to the second position pointing preferably to the back flag. If the instrument is in adjustment then the bubble will remain in the centre of its run in any position of the telescope on its horizontal axis, though it will be shown later that such a condition is unnecessary.

(3) Set up the staff on the back station focussing having already been done for eliminating parallax, note the reading and enter it, first the whole number of feet then the decimal part of the foot and without altering the "stance" of the feet repeat and check reading also bubble, keeping the body and head directly behind the instrument and in an easy and comfortable position. This completes the work on the back staff. Usually as only one staff is used the observer must wait till the staff man reaches the forward position and during the interval the observer should see that his instrument is not handled and that he does not unnecessarily walk around it, which might lead to the instrument, in unstable ground, settling down on its legs.

(4) When the staff man has reached his forward position turn the telescope on him and examine the bubble and bring it to the centre of its run, if necessary. There will be no need to refocus as the distances are equal, at any rate refocussing should be avoided as any error in the focus slide or draw tube will creep into the observations. Read and enter recheck etc.

(5) If compass bearings are to be taken the compass needle should not be unclamped till the instrument is level as it may lead to unequal wearing of the pivot. The compass reading is taken after the staff reading in each case and before the instrument is moved and carried the needle is again clamped.

(6) The measuring with the chain would take place as ordinarily on survey work. If stadia wires are read for distances then the distance of the back being read between the two outer wires the forward man is moved closer in or further away to get the distance of the foresight equal to the back. If the level wire is exactly equidistant between the stadia and wires then the mean of the stadia readings should be equal to the readings of the level wire or the central wire, which is a useful check. If there is a slight error this will be a constant, which might be calculated, if required.

From a practical point of view there is no necessity to try and get the bubble to read exactly in the centre of its run for every position of the telescope. Provided that the instrument is midway between the staves and the bubble is in the middle of its run at the instant of observing and the cross direction of the bubble is very nearly correct there will be no error in the difference of level between the two staves. In other words

the following movements of the telescope over footscrews should be sufficient if the levelling by the legs has been properly done.

(A) That over two footscrews or at right angles to direction of line.

(B) That over one footscrew or parallel to direction of line pointing to the back staff.

(C) In an end to end position to read forward staff.

The following is the order in which observations should be made and the other precautions to be taken which might be termed instrument drill, the instrument being a three footscrew pattern.

(*a*) Set up and clamp level on stand.
(*b*) Focus on to the staff and eliminate parallax.
(*c*) Roughly level by one leg of stand and press home legs.
(*d*) Place telescope in position A (supra) and level by footscrews.
(*e*) Place telescope in position B (supra) and level by third footscrew.
(*f*) Unclamp compass needle.
(*g*) Read and enter staff reading.
(*h*) Check staff reading, the entry and the bubble.
(*i*) Read and enter back bearing.
(*j*) Signal to staff man to move to forward position.
(*k*) Start chainmen chaining.
(*l*) Place telescope in end to end position, C (supra) correct bubble, if necessary by third footscrew.
(*m*) Read and enter forward staff reading.
(*n*) Check staff reading, the entry and bubble.
(*o*) Read and enter forward bearing.
(*p*) Clamp compass needle.
(*q*) Bring footscrews to the centre of their run and clamp instrument axis.

(*r*) Ink up record of chaining and offsets etc.

(*f*) (*k*) and (*l*) it is possible are dispensed with in some levelling such as check and flying levelling. If stadia readings are being taken they will come after steps (*h*) and (*n*).

150. The **errors** in levelling are due to the following causes :—

(1) Imperfectly eliminated parallax, one of the chief causes.
(2) Unequal distances between instrument and staves.
(3) Unstable ground for both instrument and staff.
(4) Non-verticality of the staff, another of the chief causes.
(5) **Bad focussing and changing focus.**

(6) Bubble leaving the centre owing to the shifting of the feet or stance in the interval between the adjustment of bubble and the actual taking of the reading.

(7) Heat and wind causing the staff image to vibrate, light and shade variations.

(8) Length of sights being beyond the power of the telescope and sensitiveness of the bubble.

151. The **mistakes** in levelling are due to the following causes :—

(1) Recording the wrong feet or decimals, usually feet.

(2) Reading to a staff held upside down.

(3) Reading the forward staff without checking the bubble.

(4) Taking one of the stadia wires as the level wires.

152. **Errors.**—1. Parallax should be eliminated by placing a piece of white paper in front of the object glass (the slide of the object glass being home and not extended) and then by moving the eye piece in or out obtaining a clear distinct and defined image of the cross wires. This temporary adjustment should not alter for the same observer and hence a screwing eyepiece is suggested instead of the plain cylindrical surface to be pushed in and out and which in time works loose in the slot and is always thus requiring readjusting.

Now with the object glass focus on the staff and if the graduations of the staff appear to move up and down when the eye is moved then parallax is not eliminated and the image formed by the object glass is not in the same plane as the wires. Correct again with eyepiece and refocus.* Imperfectly eliminated parallax will sometimes give an erroneous reading of several hundredths

2. So long as the distances between instrument and staves are equal and of moderate length (not over 300 feet except in flying levels) and the bubble is brought to the centre of its run for each observation all errors are cancelled, also error in the focussing slide, if any. As instruments can be so easily adjusted (see para. 79) and with care kept in order there is no reason why the medial position should be faithfully adhered to, in fact when "intermediates" are taken it is sometimes impossible to be midway.

3. The settling down of an **instrument** between the observations of the back and forward staff means that the back sight is lessened and the calculated elevation of the foresight will be too high or in other words if

---

* The reader should understand that there are two temporary adjustments which must be made to eliminate parallax and that although the clear image of the wires may be obtained with the eyepiece yet owing to the focus of the object glass being changed for different distances parallax will have to be eliminated at every change of focus.

the instrument had sunk one inch, one inch less would be read on the foresight and hence the reduced level of the forward staff would be one inch higher. The settling down of the instrument has therefore a tendency to cumulative error. This can be avoided by selecting the ground, pressing home the legs and taking a foresight as soon after the backsight as possible.

The settling of the **staff** between two stations will tend to make the elevations higher, that is the error is again cumulative because the backsight from the next station will give a higher reading and hence the instrument will be higher and so on. This can be avoided by the selection of good ground for the staff and also by the surveyor himself turning the rod carefully as he passes by to his next station. Errors, due to settlement of instrument and staff, are eliminated by levelling back in the opposite direction. As these errors are both cumulative it must be that, the flatter the gradient obtained in levelling, the more accurate the work.

4. Non-verticality of the staff is the commonest source of error especially in India where the staff men are uneducated and have no interest in the accuracy of the work. If the staff leans towards the observer or away from him the readings are greater than if the staff were upright. If the lean were equal for foresight and backsight the error would be compensating but such cannot as a rule be the case. In levelling uphill the foresight would be observed near the base of the staff hence the error for verticality would be little or nothing, but the backsight being lower than the observer the staff would be observed high up and the error for verticality possibly great. These errors would be compensating if the leveller returned down the hill and closed on his starting peg and though the closing error might be nil yet the height of the hill would be much higher than it really is. Errors of non-verticality can be avoided by using a suspended mason's plumbob, or by waving the staff and observing the lowest reading that is when it is upright. If the waving to and fro method is adopted the ground beneath the rod should be hard to prevent a gradual settlement and the staff man should see that no mud or dirt is taken up on the base of the staff. Any stereotyped method of holding the staff between the toes or balls of the feet with the the thumbs brought up to the level of the mouth the staff to touch the nose etc., will tend to cancel errors of non-verticality, because provided the ground is flat for the feet at any station the same angle of lean will always be observed. Another method is for the staff man to stand on one side of the staff and attend to its verticality in one direction and for the leveller to correct him for the other. The use of the plummet is perhaps the best.

5. Bad focussing leads to indistinct readings and on the forward staff being observed and the focus corrected any error in the slide of the draw tube will produce an error in reading. As the distance between instrument and staves are equal any imperfect focussing of the back station should remain for the forward station if there is any suspicion of bad fitting in the draw tube.

6. It is necessary that the bubble be in the centre of its run at the instant of reading. The reason for this has been already explained. To bring the bubble to the centre of its run and to be sure of its remaining thus till the observation is read, is best achieved by preventing any shift in the weight of the body. This can be arranged for by setting up the level so that the bubble tube is about the level of eye and leaning to one side without shifting the feet. On large and precise levels reflectors are fitted to prevent this change of " stance " and the prism levels render a change un necessary. The binocular level permits of the bubble and the staff being read at one and the same instant.

7. When the staff graduations are beginning to lose their distinctness and the staff becomes wavy owing to heated atmosphere it is advisable to stop work or to work with shorter intervals between staves. If, in a high wind, the instrument and staff vibrate, work should be suspended. Refraction is practically constant between the hours of 11 A. M. and 3 P. M. and is greatest in the early mornings and late evenings. A decided variation takes place when the instrument and staff are alternately passing from light to shade and under such circumstances the observer should take readings between staves either when they are both in the sunlight or both in the shade.

8. Length of sight is controlled mainly by the magnifying power of the lenses, condition of atmosphere and sensitiveness of the bubble tube. The staff should not be so far away so that the 100th part of a foot is not clearly distinguishable.

The ordinary engineer's level is usually fitted with a 20 second bubble, and when the bubble is not very sensitive it stands to reason the error in readings over long shots such as 400 to 600 feet is very marked and that great accuracy is not possible. If a man is quick with his instrument the question of long shots to cover ground should not be considered. An average distance of 500 feet between staves will be found to be a good maximum working interval.

In precise levelling the distance should never exceed 600 feet between staves. The following information is worthy of notice. With the binocu-

lar level a coast survey observer in regular work has occupied 120 stations in less than eight hours, the average time per station being 4·6 minutes, including setting up and dismounting the instrument and then walking from the station to station. With the average length of sights of 200 feet (400 feet between staves) as much as 200 miles of precise levelling has been done in a month. Such speed would not be possible except under perfect weather conditions.

153. In the previous para., the value of the bubble has been commented upon and as it is necessary that this should be sometimes known the following is the method for ascertaining the value of one division of the bubble tube.

If x equals the number of divisions of a bubble through which a subtended interval S in feet has been read on the staff, (d) being the distance in feet of staff from the instrument, then each division of the bubble equals $\frac{S}{xd \times \sin 1''}$

Example.—With a Y level on a level staff 200 feet distant it was found that while the bubble moved over 25 divisions of the bubble tube the reading on the staff altered from 6·75 to 6·375 or the subtended interval on the staff was ·375 feet.

Find the value of one division of the bubble.

By formula one division $= \frac{S}{x \times d \times \sin 1''}$

$= \frac{\cdot 375}{25 \times 200 \times \sin 1''}$

$= \text{Log } \bar{1}\cdot 5740 - \log 1\cdot 3979 - \log 2\cdot 3010 - \log 4\cdot 6855 + 10 = \log 1\cdot 1896$
$= 15\cdot 5$ seconds.

Or again :—to reduce to seconds, radius here being 200 feet.

Circular measure $= \frac{\pi r}{180 \times 60 \times 6} = \frac{3\cdot 14159 \times 200}{180 \times 60 \times 60} = \frac{3\cdot 14159}{3240} = \cdot 001$ very nearly.

∴ 1 second subtends on the staff 001 feet (very nearly.)

∴ 375 seconds will subtend ·375 at 200 feet but bubble moved through 25 divisions and therefore each division of the bubble is equal to $\frac{375''}{25} = 15''$.

154. **Care of instrument,** staves and final cautions.

(1) Note the position in which the instrument lies its box and take it out gently lifting it by its lower frame work not by the telescope.

(2) Place the instrument on the stand clamp or screw it firmly on its stand and shield it from the sun as much as possible. Examine instrument and stand for shake.

(3) Avoid jars in the preliminary levelling by the legs of the stand.

(4) Do not unclamp the prismatic compass needle till the instrument is levelled and then clamp it before carrying or putting the instrument away.

(5) Always bring the footscrews to the centre of their run when work at a station is completed.

(6) If the instrument has a clamp and slow motion screw, the instrument should be clamped before it is carried or put away to prevent unequal swinging of the axis on the pivot and thus unequal wear.

(7) Do not set up instrument on a smooth floor or pavement without caution as the legs may spread-eagle and let the instrument down. Be careful how you carry an instrument through an open door or under trees.

(8) Do not meddle with the lenses or clean them with silk or muslin; wash leather is best. If the object glass is to be removed then its position as placed by the maker must be scratched on the edge of its ring so that it can be returned to its exact position. First class instrument makers usually etch a line for guidance.

(9) In adjusting the bubble or diaphragm do not tighten one screw before loosening the opposite one.

(10) Do not force screws. If footscrews jamb they either require attending to as regards tension screws or may work easily in a different set of slot holes. If footscrews are hard to move then they are either very much out of the centre of their run or the slots in the stand have been damaged so that the distance between slot holes do not agree with the distance between the footscrews. Some makers dot the footscrew and the particular slot of the stand in which that footscrew should be placed. However the jambing of footscrews is a fruitful cause of bad levelling, and as it is mostly due to the slots of the stand the "screw on instrument" is a much better arrangement and this has been advised under "choice of instrument." The footscrews should move true axially that is, if the telescope is placed over one footscrew, the instrument being more or less level, on the footscrew being turned the image in the telescope should move vertically up and down and not sideways as well. The effect of this error is almost nil in levelling but is very marked in angular work with the theodolite.

(11) The instrument should be replaced in its box very carefully and in a dry condition, the lid of the box being brought quietly down without jar or forcing and the clamp screw tightened. If the box is to be caried over a journey then packing should be well wedged in to prevent the instrument being shaken. If the instrument is to be put by for any lengthy period where dust accumulates such as in India, paper should be pasted over all cracks.

(12) The staff man should never be permitted to approach too near the instrument while carrying the staff.

(13) If there is no sunshade to the object glass make a temporary one out of paper and a pin. Avoid casting a shadow on it with your hat or umbrella unless you can make sure that the whole of the object glass is shaded.

(14) Keep still when observing and take up an unstrained attitude with the hands off the instrument.

(15) Do not tire the staff man by keeping him on the "qui vive" when it is not absolutely necessary.

(16) Staves should be hung up or laid face to face on the ground. They should not be leant against walls or trees and should be put away dry and freed from mud and sand.

(17) Attend to parallax, stability of ground for instrument and staff, verticality of staff, the bubble in the middle of its run at the instant of reading the staff, the instrument midway between staves, the reading of the feet first and the decimals next, remembering that if you "make sure of the feet the decimals will follow" and see to their correct entry in ink.

(18) Erasures are *never* permitted except in ink when the wrong entry should be neatly crossed out and the correct one entered above, initialled and dated. Pencil entry is never allowed in any original record.

The fulfilment of these precautions will produce the best of results whether the instrument is in adjustment or not. Finally use the instrument so as to obtain good results and not as if you expected it to give them.

For ordinary check levelling if the chain is used a squad of 5 men is necessary, without the chain, 3 men.

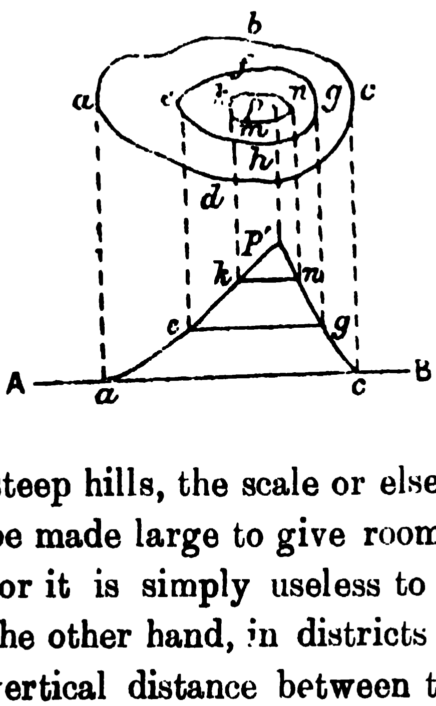
155. **Contouring.**—Contouring means tracing on the surface of the ground horizontal lines with a fixed vertical height between adjacent lines; the vertical height will vary with the nature of the country contoured and

the object for which the contour survey is required, and is fixed accordingly. The positions of these horizontal lines are surveyed and protracted upon a map, in the same way as any other boundary lines.

Contour lines are either traced round isolated features of ground for designing plans for drainage, buildings or other engineering purposes, when the correct features and levels of the country are required to be seen at a glance, or over a whole tract of country, with a view to giving a mathematical representation of the surface of the ground in connection with a national, or other extensive and accurate survey.

Let the following plan (*Fig.* 65) represent the contoured top of a hill, the figure below an elevation, parallel to the line AB. Then each of the lines in plan would be seen in elevation as follows:—

Fig. 65.



abcd as *ac*; *efgh* as *eg*; *kmn* as *kn*; and the top as *p*; the vertical heights between *a* and *e*, *e* and *k*, being all equal, say, 1, 5, 10, or more feet apart as circumstances require. It will be seen that the steeper the hill is, the nearer the contour lines approach each other in the plan; hence in contouring steep hills, the scale or else the vertical distance between each line must be made large to give room for the lines to be clearly drawn on the plan, for it is simply useless to survey lines which cannot be plotted; and, on the other hand, in districts which are nearly level, contours having a great vertical distance between them would be of little practical utility. When contour lines run for long distances and close together, it is a great help, for ready inspection of the plan, to make every fifth line or so either thicker or of a different color.

In contouring a hilly country, the watershed of the spurs will always be found to have the most gradual and even slope. It is the best plan, therefore, to run a line of levels down each, fixing pegs at the point where each contour line crosses it, pegs on the same contour being similarly numbered: to do this the levels down each spur must have been properly connected, and this is conveniently done by running an auxiliarly line of levels from a point in the line down one spur to some point similarly placed on the next spur. The reduced levels down each spur having been thus connected, the contour pegs (say 5 feet apart) down each spur can now be fixed. The instrument is then put up over each peg in succession, and, its height having been taken by a levelling staff with a vane affixed a man with

the vane is sent to any point between the two spurs which it is wished to fix, and he moves the vane staff up or down the hill side till the cross wires of the level cut it; this point is then fixed and its bearing read off: in the same way any required number of other points in that contour is determined. From the corresponding contour peg on the other ridge, the bearings of these points are again read with a prismatic compass, and plotted on the map with reference to the pegs on the ridge by means of the cross bearings, the position of which pegs must be accurately fixed by a survey. The positions of the pegs may also be fixed by running traverses with the theodolite between known points along the line of each contour, and taking an off set to each peg in succession; when the country is moderately level this is much the most convenient plan to adopt. If there is no instrument for reading the vertical angles, the horizontal distance of the line of pegs on the watersheds may be fixed as follows: Let r=the measured distance between two consecutive pegs on the watersed, h=the difference of level, then $\sqrt{r^2-h^2}$=the horizontal distance between these two pegs; it will be seen that these watershed pegs should be made to run in as straight lines as possible to facilitate the survey of them.

The reflecting hand-level, or the contouring glass with a prismatic compass, is also well adapted for filling in the points between the watersheds.

156. **Contouring large areas.**—The above method is for very distinctly marked ground and of small area, but for canal irrigation and drainage works in ordinary country, the slopes are not perceptible to the eye at all clearly, if at all, yet a perfect contour map may be made with no difficulty. Lines of levels must be taken running parallel or nearly so to each other and at any convenient distances apart, the distances varying with the nature of the country and the object of the survey. The stadia for reading distances will be found a great time saver. After plotting the reduced levels on the plan of the field work, contour lines may then be drawn on the plan by interpolation joining the points of equal elevation and at any convenient height apart. If the drainage lines of the country have also been traversed and plotted, a fairly approximate series of contours may be traced. Should greater accuracy then be required, these lines may be levelled, the bearings of the lines being taken from the plan, and any requisite alterations made; but as a rule in the plains of India, the plan of a tract of country contoured in the above manner in sufficiently accurate to determine either the main line of a large canal, or the direction of any of its distributing channels.

For less accurate work, such as is required in military sketching, in making a preliminary investigation for a hill road or in running in intermediate contours, either a protractor with a string and weight attached, or a reflecting hand-level, will suffice. Such instruments are easily used, and being adapted to the size of one's pocket are very handy.

In connection with contouring that portion of the chapter on engineering surveys which treats of canal surveys should also be read.

CHAPTER VII.

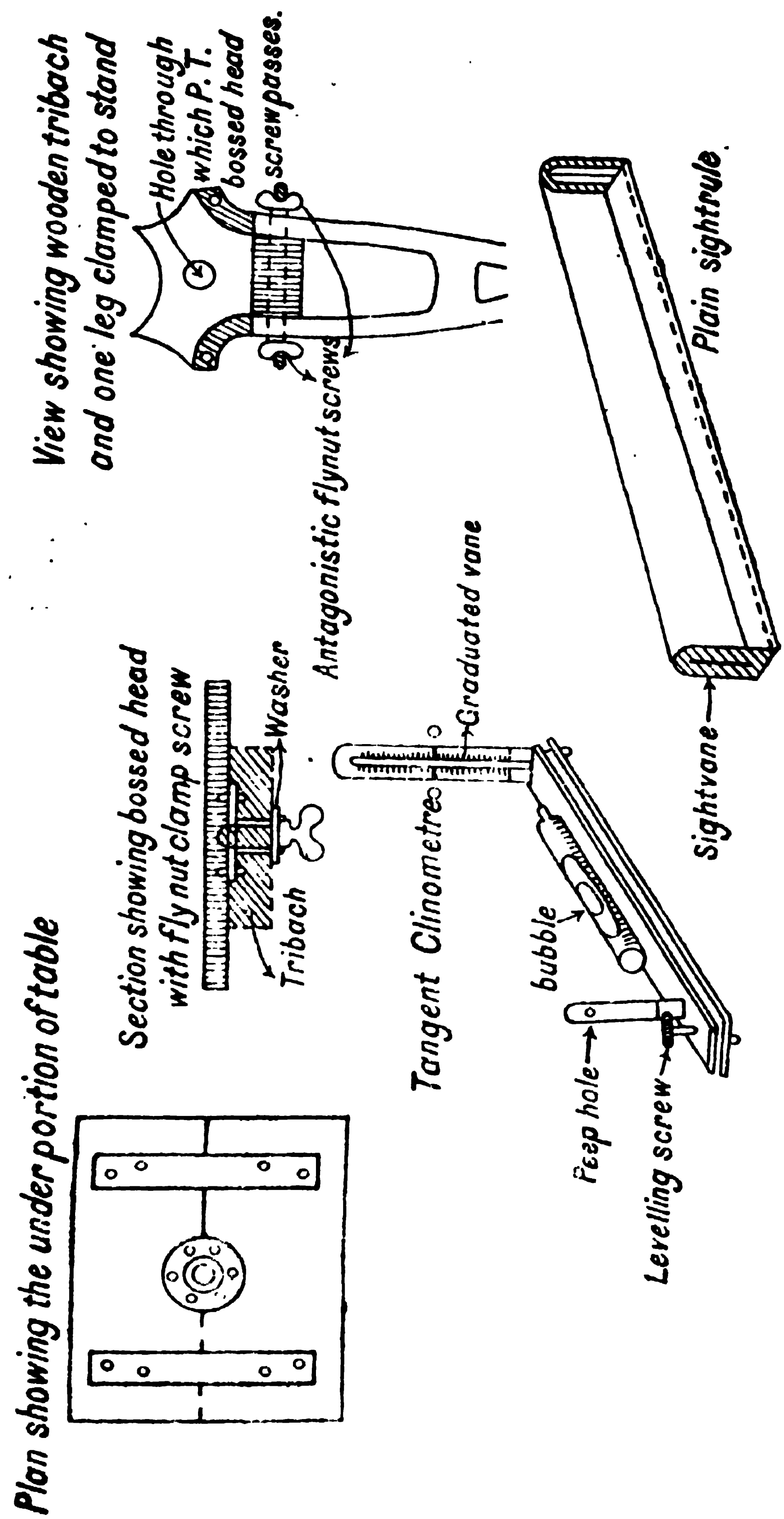
PLANETABLING.

157. **The planetable** and its method of surveying is due to the Survey of India who originated it and who still use the simple table, plain sight rule and tangent clinometer. These are considered the best under the climatic conditions prevailing and in the hands of the Indian staff which is now almost entirely employed on this class of work.

The scale of the survey is a great factor in determining as to whether the planetable is to be used or not. The smaller the scale, the greater the desirability of surveying with the planetable, especially in hilly ground. On very large scales, where extreme accuracy is required together with records of distances and angles, the planetable loses its value, though even here, it may be judiciously employed. In dense jungle and undergrowth it has been thought that the planetable is an impossible instrument and yet all the forest areas of India were surveyed entirely by the planetable and it is doubtful, whether these areas could have been mapped by any other system, except at a great expense of clearing, plotting and adjusting.

Two kinds of planetable equipment need only be described, namely (i) the simple planetable and stand with its plain sight rule, tangent clinometer and magnetic compass, and (ii) the elaborate aluminium table with telescope alidade, or sight rule head as it is sometimes called, see Chapter II, Part II. All other planetable equipments might be said to be either an elaboration of the one or a modification of the other; the former might be said to employ planetabling methods pure and simple and the latter to combine with such methods tacheometric or stadia methods.

158. **The simple planetable equipment and its methods of survey.**—The table, see fig. 66, is made up of two pieces of well seasoned pine about ¾ inch thick braced underneath by two battens of harder wood (usually teak) having slot holes to allow for contraction and expansion. In the centre underneath is fitted a bossed head of brass which when placed on the tribach of the stand is clamped to the tribach by means of a fly nut screw having a washer. The split legs of the stand are connected to the tribach by a bolt passing through two holes and wing of the tribach. This bolt is wormed at each extremity and two antagonistic fly nut screws secure the legs and hold them tightly clamped. This antagonistic action has the tendency to squeeze the extremities of the legs to the tribach and


Plan showing the under portion of table
Section showing bossed head with fly nut clamp screw
Tribach
Washer
View showing wooden tribach and one leg clamped to stand
Hole through which P. T. bossed head screw passes.
Antagonistic flynut screws
Tangent Clinometre
Graduated vane
bubble
Peep hole
Levelling screw
Sightvane
Plain sightrule

not to split the wood along the grain, as often happens with the bolt head and nut device.

When the planetable is placed on the top of the tripod so that the bossed head passes through the hole it is screwed home and clamped by the screw and the table is complete. There is no clamp, slow motion or footscrews with this equipment, and under ordinary circumstances no necessity has been found for them.

159. **How to mount paper so as to obtain a smooth surface** (see also paragraph 3). Cut a piece of white or blue hand made drawing paper so that it is roughly ½″ smaller all around than the table. Next cut strips of strong foolscap, or cartridge paper, about 4″ in width and with a total length of the perimetre of the table with a little to spare. Prepare some thin paste and rid it of all lumps and having *well soaked* the strips of foolscap apply the paste on one side of the strips only and keep them handy. Pass the drawing paper through a tub of clean water by holding two corners of the paper, care being taken that the surface of the paper is not bruised or cockled. Surplus water should be allowed to run off and the paper placed right side up as centrally as possible on the table. If there is an assistant the paper being held by four corners should be allowed to first touch the centre of the table and then the edges laid down. No sponging should be attempted as it removes the sizing. Now take the thin strips already pasted and paste down the edges of the drawing paper by overlapping it and turning the outer edges of the strips beneath the table. Put away in a cool place to dry. The pasting down of the thin strips should be done as soon as possible as no portion of the drawing paper should be permitted to dry before this operation has been performed. It may be necessary from time to time to apply a little paste here and there during the drying process. If the quality of foolscap used is found to be weak, when the tension due to contraction of paper asserts itself, then tracing cloth is an excellent substitute. The map can be removed by passing a penknife under the paper.

If the drawing paper is to be mounted on cloth a piece of open mesh cloth about 6″ larger all round than the top of the table should be cut and well rubbed in water to rid it of starch. The cloth should next be rinsed fairly dry and pulled by opposite corners with a zigzag motion to stretch it to its utmost. Place this cloth on to the table and apply paste to the edges and stick the cloth all around to the *underneath* portion of the table. This done apply paste to the exposed cloth, on the top of the table, evenly and free of all lumps. Take the drawing paper previously cut

smaller by half an inch than the table and pass it through a tub of clean water and place it centrally right side up on to the paste covered cloth and with a piece of clean blotting paper between the hand and the working surface of the paper press the paper from the centre outwards in all directions.

Paste thin strips of foolscap along the edges to protect them from being torn up by the sight rule. The board should be left in a cool place to dry. To remove the map cut around the edges and with an office ruler roll the drawing off the board. The paper mounted over cloth gives a much better working surface and the map of course will last much longer.

Good results in mounting will aways be obtained if the paper is laid well to start with and the edges dry before the central portion. The board should never be wetted as it is bound to give trouble later.

Two men can usually do as many as twelve standard size planetables in an hour, and if such work is done at about sundown or a little earlier, by next morning, unless the weather is very damp, the paper will have regained its smooth even surface and if not absolutely dry will at least be fit to plot on. In India the difficulty is how to keep tables from drying too quickly and therefore the drying is usually done over night. Such implements as clamps, drawing pins, and pin strips are a nuisance, as they obstruct the proper working of the sight rule and after all are of little or no use in a high wind. The planetabler who wishes to do good work and retain his temper will do well to consider a quarter of an hour well spent in mounting his table.

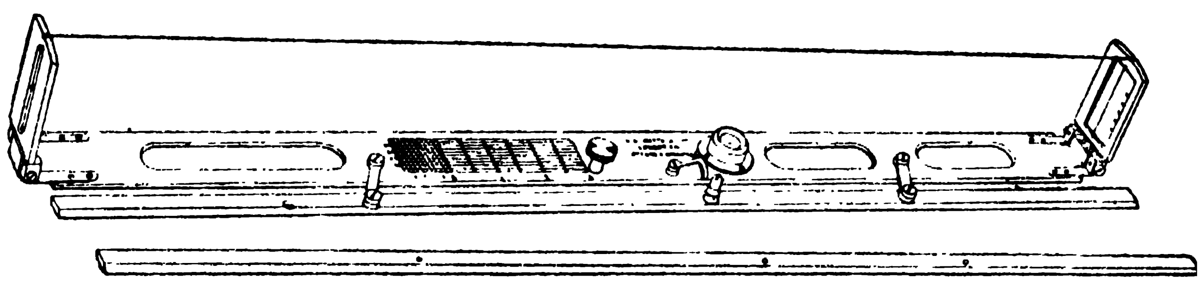
160. **Sight rule and magnetic compass.**—The ordinary sight rule is a piece of flat wood about 2″ broad and ¼″ thick and 20″ long at each end of which is mounted a brass vane. If the planetabler is right handed the fiducial edge is on the right and the nearer vane will be the sight vane and further vane the observation vane. The sight vane is pierced with a slit about 1/16″ wide or less and the observation vane has a broad aperture in the centre of which is stretched vertically either fine brass wire or better still horse hair, which can be renewed at any time by being plugged in by small pegs or a whittled match.

The conditions required in a sight rule are, that on a line being drawn along the fiducial edge when the ruler is turned end to end and placed along the line, the edge should lie evenly along the line and also that the line between the sights or the line of sight should be parallel to this ruling edge. For objects much above or below the horizontal plane of the table a thread is stretched from vane to vane and high objects are intersected

through the peep hole along this thread and low objects by the thread intersecting the object on the wire of the observation vane.

The illustration (fig. 67) is of an improved pattern sight rule devised by the author. It is of electrum, has a separate slide for its fiducial edge, bubble for levelment of table, collapsible vanes, engraved scale and points for rough stadia measures. The button, in the centre or at the point of balance, is for lifting the rule. Messrs. E. R. Watts & Son, the makers, call it the "Indian" pattern.

Fig. 67.



The magnetic compass is of the ordinary trough pattern with a needle 5″ long.

162. **The tangent clinometer.**—Is probably essentially an Indian Survey pattern instrument and for small scales with eye contours by ~~is~~ interpolation, is sufficiently accurate.

A description of the instrument is as follows:—There are two vanes mounted on a bar which is pivotted at one end to the base plate. One vane is the sight vane with a peep hole and the object is intersected on the other vane along the vertical aperture against a certain graduation. This vane is silvered and graduated on the left as you look through the peep hole to degrees and ¼ degrees and on the right to natural tangents to an arc of 8″ radius with the peep hole as a centre. On the observer's side of the sight vane is a milled head screw which passes through the plate to which the vanes are attached and works against the base plate. This screw thus elevates or depresses the peep hole. Midway between the vanes and attached to the upper construction of the instrument, that is the upper plate, is a spirit level, and the instrument is in adjustment when, with the milled head screw, the spirit level is brought to the centre of its run and the line of sight through the peep hole and the 0 graduation on the observation vane is a true level line. Elevations are read above and depressions below the 0 graduation, that is to say, the graduation is

upwards and downwards from 0. The whole instrument is made of brass and is lacquered dull and can be folded and put away into a small case. It is not easily damaged and is in many ways a very desirable instrument.

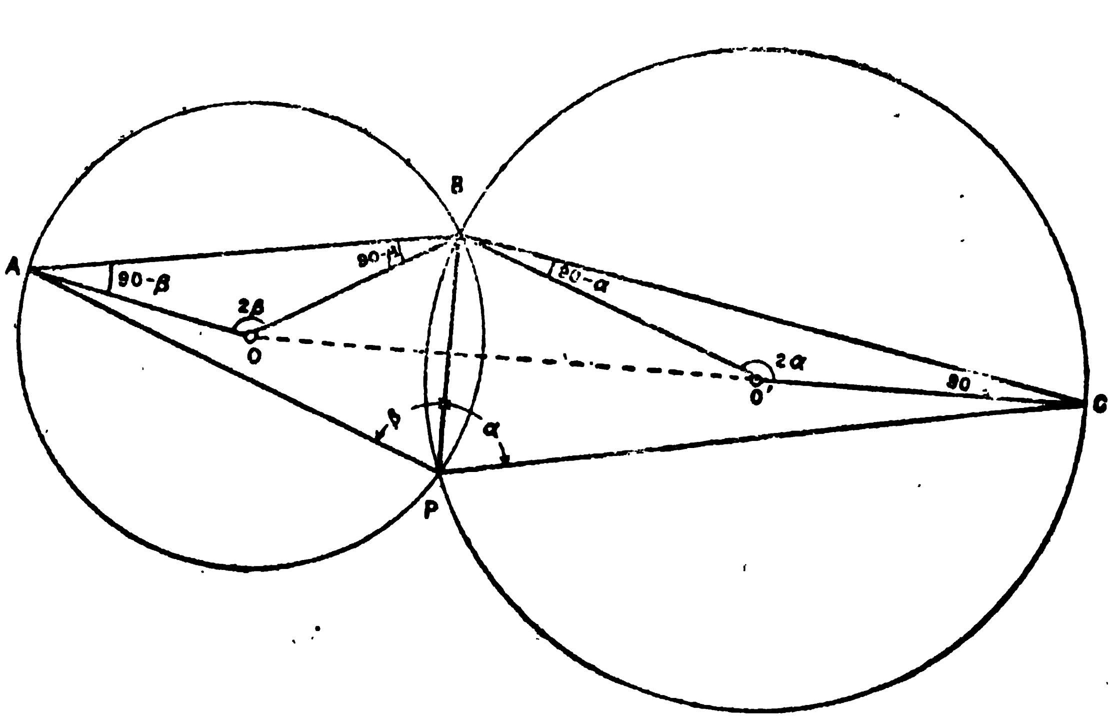
To find a difference in height, (see para. 101) between an object and the height of the eye or table the instrument is levelled and the object read for the natural tangent, and this natural tangent multiplied by the horizontal distance intercepted between the object and the table, and corrected for curvature and refraction, gives the result required. The intercepted distance is taken off the plotted map on a scale, on which scale is usually marked the correction for curvature and refraction (co-efficient taken generally as ·07).

163. The simple planetable and its accesories have now been explained and survey work with it may be classified as (i) a planetable survey by magnetic bearings; (ii) a planetable survey by the back and forward ray system; and (iii) planetabling proper by intersection and interpolation based on trigonometrical or theodolite traverse data.

The two first stated methods are useful in their way and at times probably the most effective means of doing some classes of ground, but before these are entered into in any detail it is essential that the graphical method by which the planetable solves and finds its position by interplolation or resection should be explained as it is here that it possesses its greatest asset and hence its extended use in topography.

Geometrical proof.—If A, B and C (fig. 68) were three known points and P a position at which the table is situated (the whole table for most scales

Fig. 68.



may be taken as a point) then if the table were set in true azimuth, rays

drawn from the projections of A B and C will meet at the point P, when the angles APB and BPC are known. The point P, with respect to AB will be situated on the circumference of a circle drawn through ABP, and the point P, with respect to BC will be on the circumference of a circle drawn through PBC. The intersections of the two circles will be at B, a point common to AB and BC, and P which will be the required point.

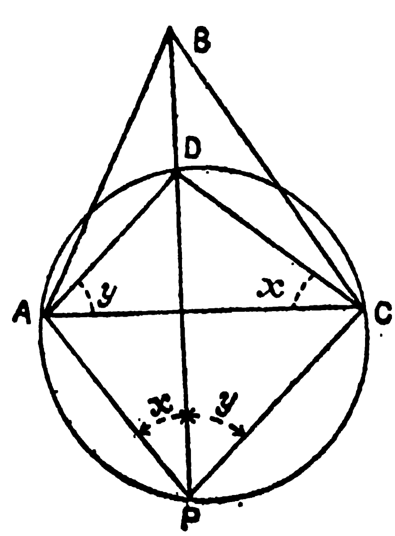
By Euclid III, 20, the angle at the centre of a circle is twice the angle at the circumference standing on the same arc. Let AB be this arc. If we make the angles BAO and ABO each$=90°-$APB, the angle AOB will equal twice APB therefore O where AO and BO intersect, is the centre of one of the circles required, and similarly if the angles ÓBC and BCÓ are made equal to 90°—B P C then Ó is the centre of the other circle; with a radius OA and a radius ÓB draw the two circles, and P the intersection of the two circles other than B will be the required point.

When one of the angles is obtuse, the complement of it is to be used and the angle thus found protracted on the opposite side of the line joining the two known points to that on which the required point P is.

It follows also by Euclid III, 22, that if the angles ABC and APC are together equal to 180°, that the centres O and Ó will coincide and the solution is indeterminate, and hence we obtain the rule that if A B C and P are points situated on the circumference of a circle the point P is indeterminate.

164. **Trigonometrical proof.**—Let A B and C be three known points and P the station from which the angles x and y have been observed.

Fig. 69.



Through the points ACP pass a circle and let this circle cut the line BP in D Join AD and DC. By Euclid III. 27 the angle DAC $=$ y and angle DCA $=$ x. Then in the triangle ADC the side AC and the two adjacent angles are known (AC is known as every function of the triangle ABC is given) and therefore the side AD is known.

In the triangle ADB since AD and AB are known and the angle BAD $=$angle BAC$-$angle DAC therefore the angle ABD is known.

In the triangle ABP the angle BAP is known, since it is equal to $180° - (\text{angle ABP} + x)$, and the side AB is known, therefore PA and PB are found. In the same way PC can be found. If B coincide with D then the point P is indeterminate. For tabulated proof suited to logarithmic computation reference should be made to Chapter I, Part II, on *Triangulation* (see *problem of fixing a station from three known points*).

From the foregoing proof it will be seen that if the angles at P are observed with a sextant or a theodolite and the angles plotted or protracted on a piece of tracing paper that the point P can be pricked through when the lines PA, PB, PC pass simultaneously through the points A B and C.

165. On reconnaissance work the tracing paper device is sometimes resorted to and the method is as follows :—On the planetable being roughly put into orientation, rays from any point on a piece of tracing paper or cloth are drawn to three or more known points. The tracing paper is then shifted about till the three rays pass simultaneously through the points from which they have been drawn, when the point which is the vertex of the rays and was an assumed position, becomes now the true position and is pricked through. Then with the point thus found and the sight rule set on the projection of this point and the projection of the most distant known point, and on the distant point being intersected, the table will be in true orientation or true azimuth, as it will hereafter be termed.

166. An instrument called the **station pointer** serves the same purpose as the sight rule of graphically solving the three point problem but the values of the angles must be known and protracted on the arc to which the three arms are attached, the central one being fixed and the two outer ones being movable. Such an instrument is largely used on marine and hydrographical surveys when points on the shore are known and the angles between them are observed with a sextant. This fixes the position of the observer, say in a boat and on a sounding being taken the depth of water at a certain point or distance from the shore line is found.

167. To find the point graphically with a planetable and sight rule there are several methods, but none so easy as the trial or "**triangle of error**" method which has been in practice in India for at least half a century to the exclusion of all others.

168. **Bessell's** method or the ABC solution finds the point after four or five movements of the table and this method fails very often since the intersection of two of the rays may fall off the table, or the intersection

point which is used for setting on a third point, is so close to the third point, that the setting being short, the azimuth of the table is faulty. Long pencil lines have to be drawn on the table and a succession of these for every fixing would soon make the paper and map dirty. Bessel's solution is based on the geometric principle "that in any inscribed quadrilateral the angle made by one of the sides with one of the diagonals is equal to the angle made by the opposite side with the other diagonal."

169. There is the tracing paper method used on reconnaissance work (see previous paragraph) and which is more or less approximate and need not be entered into further here.

170. Another method is that of **Llano** in which the operator is required to bisect the line AB (see fig. 68) and then draw a perpendicular, sighting the line thus drawn on B, &c., &c. This method is useful to know possibly only from an academic point of view and as a practical method must be held inferior to the trial method, since a certain amount of geometrical construction is involved into which there must necessarily creep some constructional error and further the method is unwieldy necessitating large compasses, drawing of arcs, &c.

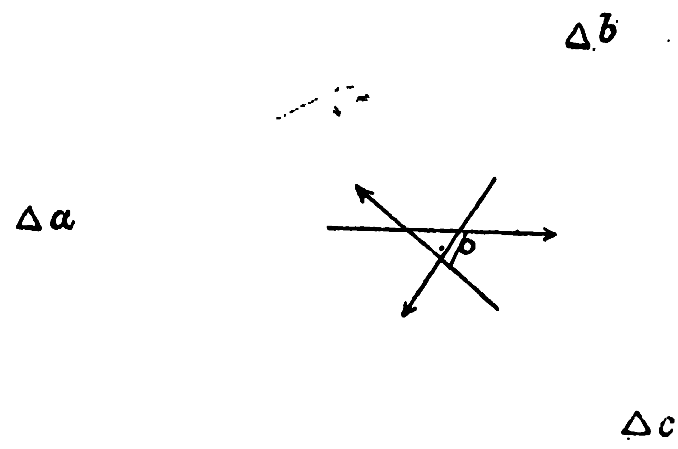
171. In the trial or **triangle of error** method two conditions arise when P the point sought is situated (i) *within* and (ii) *without* the triangle formed by the three known points.

If A, B and C are three known points on the ground represented by a b and c their projections respectively on the table, and if the table is in true azimuth with respect to these three known points then the rays drawn through a b and c with the directions of A, B and C will intersect at a point p which will represent P on the ground. This rarely happens since the table cannot be set in azimuth at the first trial, even with a magnetic compass the variation of which is known, and hence instead of obtaining an intersection at p, a triangle is formed, which is known as the triangle of error. This triangle of error will be great or small depending upon how much or how little the table is out of azimuth.

Condition 1.—The condition or case of the point sought being situated **within the triangle** of the three known points leads to the solution of the triangle of error from *within*, that is to say the point p on the table will be *within* the triangle of error and will be in a position such that the perpendiculars from the point p to the rays drawn from a, b and c, will be in proportion to the distance of the point p from the points a, b and c respectively.

In figure 70 the point p is about equidistant from b and c and a little further away from a, and as p is *within* the triangle formed by joining a b and c then p will be approximately as given. If now the rays are rubbed out and the sight rule set on p a, and A be intersected, the next trial will fix p or in other words the rays from a b and c will intersect exactly at p. If they do not then a second and nearer approximation is made and so forth. Generally two approximations are sufficient to find the exact point p. Again if the estimation of p could be made correctly at the first trial one approximation would be sufficient.

Fig 70.

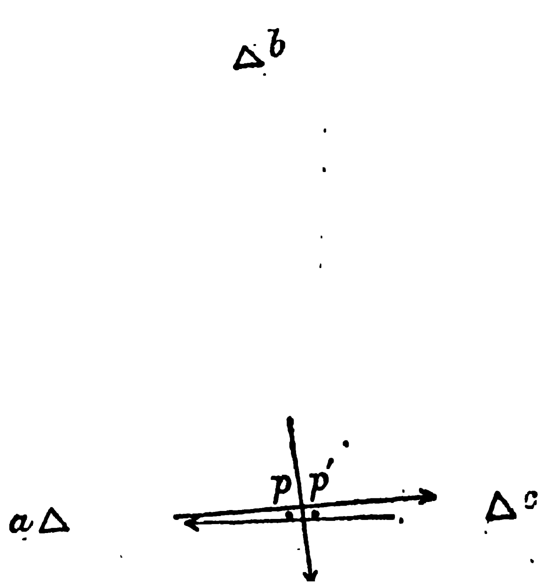


The position of p as found *within* the triangle is strong, but possibly the strongest position is when p is very near one of the points a b or c.

It should be noticed that if arrowheads are affixed to the rays as drawn *towards* the observer the point p falls always to one side; in the case in the example always to the left of every ray. This will be useful to remember later on.

Let the condition now be considered when the point sought lies within the triangle but near the line joining the two points, Fig. 71. Let the rays be drawn as in figure and let arrow heads be affixed. On the point p being found and the board orientated the direction of movement of the error in the ray must be proportionate to the distance away of the points and must be all in one direction; p therefore is the point and not p', as p' is on the reverse side for one ray. The value of the position of p is strongest when the ray from b is more or less at right angles to the rays from a and c and weakest when b lies near a or c for the intersections then would be very acute. The value of p increases in strength also as b approaches p.

Fig 71.



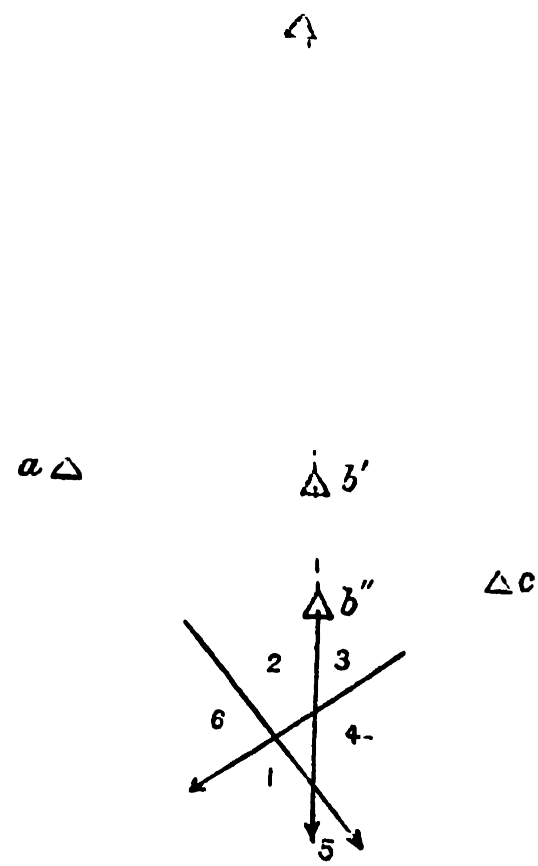
The same solution holds good and the relative importance of strength holds good when the point p is just without the triangle. It will be noticed that although p in both cases falls to the left of all rays yet in one case it is situated *within* and in the other case *without* the triangle of error.

Fig. 72.

Condition II.—When the point sought is **without the triangle,** Fig. 73, formed by the three known points then the point p will fall without the triangle of error formed by the rays drawn from a b and c on A, B and C.

To return to the theory of arrowheads and the rotation of the board it can be seen, Fig. 73, that p cannot lie in the positions 1 and 2, 3 or 5 since in each case one of the rays gives an apparent contrary motion to the other two. There remains the positions 4 and 6 where the rays rotate in the same direction. Again as the condition of proportional distance to the rays must also be considered, for p to be in a position at 4 is impossible, since b is further away than a and c, in about the proportion of $2\frac{1}{2}$ to 1, and therefore the position at 6 is the only possible position and p is therefore approximated at 6 as about 1, 1 and $2\frac{1}{2}$ units from the rays a c and b respectively.

Fig. 73.



Let now the position of b be changed to b' then again with the above reasoning the position 6 becomes impossible and the position of 4 possible. The reader will now say, since such is the case, there must be some position of b when p will neither be in 6 or in 4 but some where between, exactly so, and

when it is neither one thing nor the other, is when *b* is so situated that *a b c* and *p* are on the circumference of the same circle, and hence *p*, as has been proved, is indeterminate.

As to whether the point is at 4 or 6 the following rule will make it clear "when the point sought is without the triangle, it is always on the same side of the line from the most distant point as the intersection of the other two lines."

The further *b* is away from *p* the weaker the value of the position and the position only becomes a strong one when *p* is very near *b*. In Fig. 73 if b'' be the near position it will be seen that since b, b' and b'' are all in one and the same straight line the triangle of error remains the same but the approximation of *p* will be close to the ray from *b* and occupy a much more definite position than when at b' and so on. These two conditions practically include all the cases which will occur in practice, and whether the solution is a strong or a weak one, should be thoroughly understood.

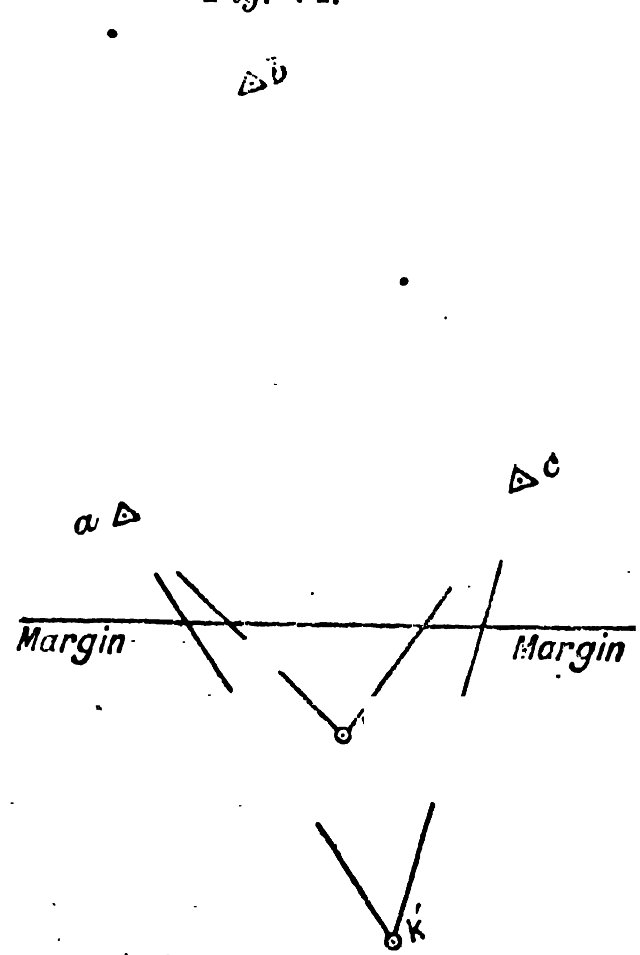
In speaking of the three point problem it must not be taken for granted that if a fourth point is seen it must not also be used, on the contrary, a fourth ray may be extremely useful in the solution and the point when found will be above suspicion.

172. The triangle of error as has been stated depends entirely on the azimuth of the board and with a magnetic compass the variation of which is known to be fairly constant, the point sought should be found on the first and certainly on the second approximation, but the planetabler with a little experience will generally find two points out of the many around him which will be found in a line or can be placed in a line by moving the table, and with the sight rule on their plots, the board can be brought into exact orientation by intersecting the more distant one of the two, and thus the position sought is found almost at once by resection from one other. Again if two points are not exactly in line and if it is considered that a line drawn from the distant one will pass by the other at 50, 60, 100 or 200′ as an offset judging by the eye and the allowance is made in setting the sight rule it will be found that one further approximation, if any, is sufficient. When a planetabler says, "I am between these two points and I have this point near and at right angles," "or these two points are in a line and this other will give me a good cross intersection" it may be taken for granted he knows a good deal about the art of interpolation or "fixing" which term will in future be used as an abbreviation for fixing the position of the table.

173. Here it might be noted that, although the fixing *outside* the triangle is geometrically true, yet as many issues are involved:—that of poor plotting, inaccurate co-ordinate squares, unequal expansion and contraction of table, inaccuracy in the fiducial edge of the sight rule and lastly small differences in the fixing of the planetabler's auxiliary points, some or all of which are being used, that this class of fixing should be adopted with caution, since any inaccuracy tends to intensify the weakness of such a fixing; whereas a fixing within a triangle if it will not solve absolutely owing to some slight errors, then at least the error in position is ultimately confined to a very small triangle somewhere within which is the true or mean point to be used. The fixing without the triangle is always avoided by the expert planetabler who foreseeing such a contingency throws out a point outside his margin of work, it may be, so as to place him always *within*.

In figure 74 the contingency is illustrated where work up to a certain line or margin was necessary. A point K and a point K′ are intersected from a and c and although there are only two rays to K and K′ their positions are so to speak approximate but K could be used with absolute confidence and will give no error in a fixing even if K or K′ were a little incorrect so long as the position of the table is within the cone of the two rays to K or K′ respectively; in any case a fixing with a, c and K or a, c and K′ would be *within* the triangle, more accurate than the fixing *without* the triangle with the points a b and c which, since b is more distant than a and c, is geometrically weak. Some surveyors place an implicit belief in the solution without the triangle, and it is not the writer's intention to say they are wrong or incorrect; he merely states his preference and in his personal experience he

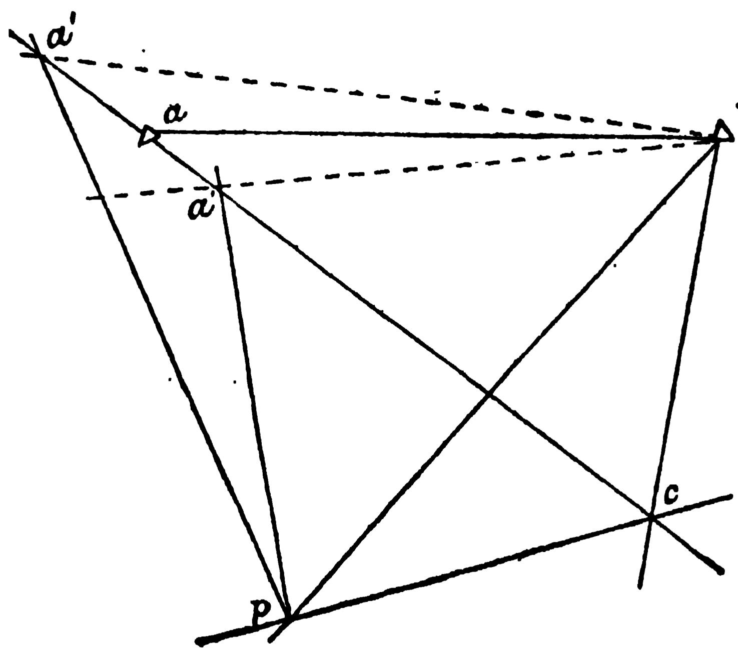
Fig. 74.



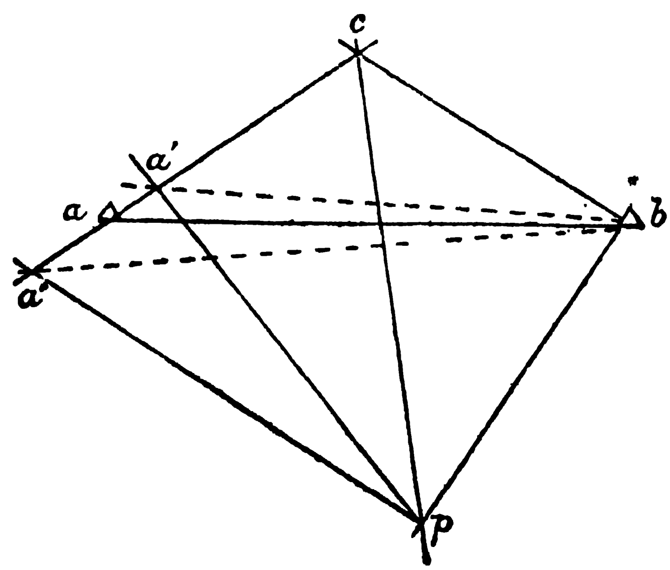
has invariably avoided the fixing without the triangle except when the middle point is much nearer than the other two used.

174. **The two point problem.**—Let A and B be two inaccessible objects as the spires of temples or hill peaks. They may, as in case I, be both on one side of the planetabler or in case II one on each hand. Let the plots of A and B be given as a and b. At any position C on the ground, preferably on fairly high ground or in a conspicuous position, set up the table and with the compass bring the table into approximate azimuth. Sight A and draw a ray ac and again sight B and draw a ray bc and consider c, the intersection, as the plot of c. With the sight rule on c draw a ray cp to another object P and produce the ray for back and forward setting. Leave a mark at c and proceed to P. At P set up the table and with the sight rule along the ray cp intersect the object or flag at C.

Case I, Fig. 75.



Case II, Fig. 76.



This back and forward setting over positions P and C must be very carefully done. Now intersect B and draw a ray, bp to cut the line cp in p. With the sight rule on p intersect A and draw a ray and if A is intersected in a, p is the true position, if not, let pa' be the ray, cutting ca or ca produced in a'. Join ba'. The angle $a'ba$ will represent the azimuthal error of the table, and if we can disperse this error we will have three rays to fix the position of P one from a, one from b, and the third being the true meridian.

Place the sight rule on the line $a'b$, sight and note any object intersected, next place the sight rule on the line ab, unclamp the table and clamp it again, (with the sight rule on ab), on the object previously selected as being intersected on the line $a'b$. The table will be now in true azimuth; so intersect from a and b and the true position of P will have been found.

Fig. 77.

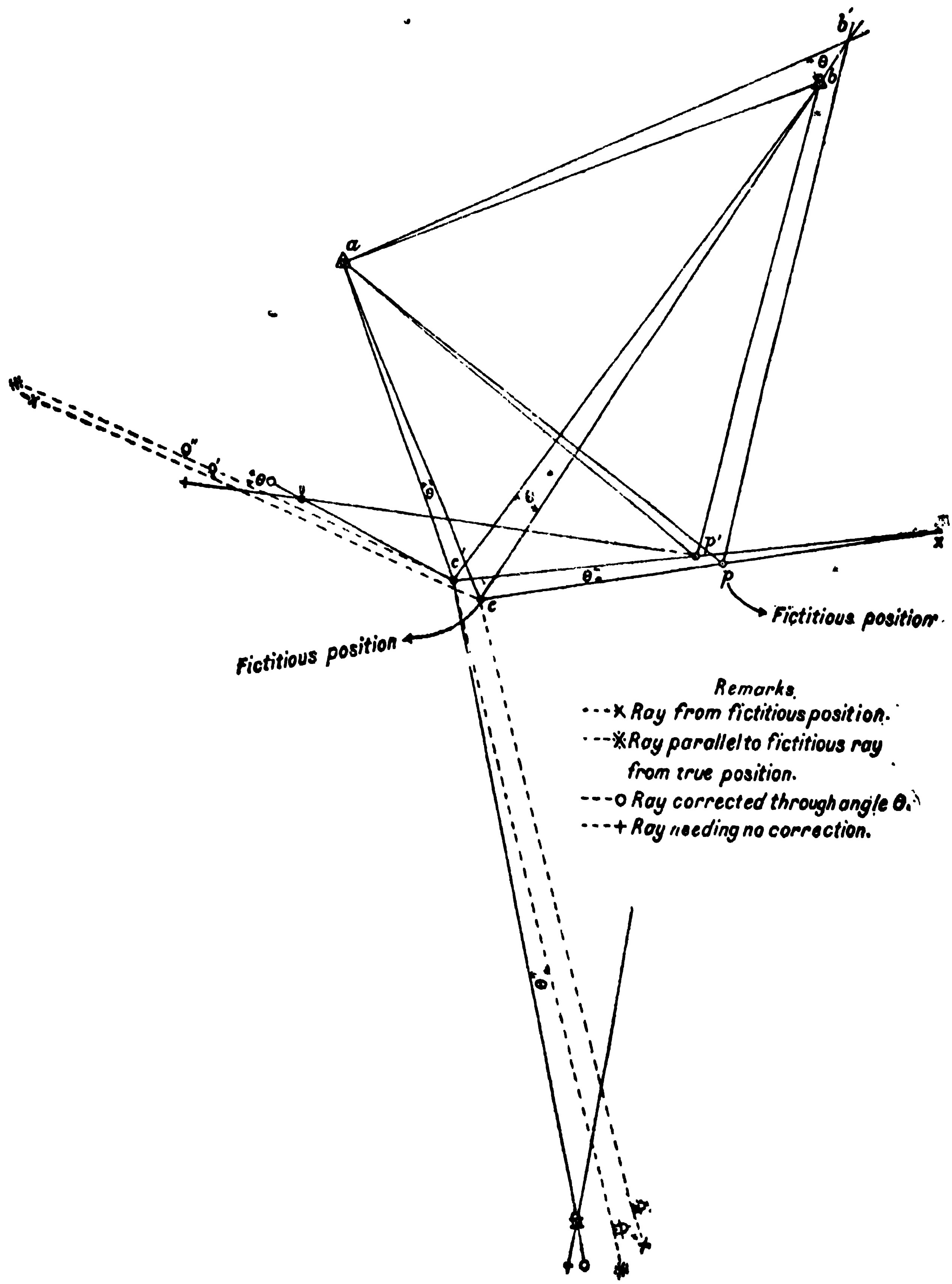


Fig. 77 shows an actual case of the fictitious position of p becoming p' and c corrected to c'.

To correct c to c'.—From p' draw a ray to C and the ray will no longer pass through c but c' and the true position of C must exist along the ray $p'c'$. Now the angle of correction $= \theta = b'ab$ and this angle is clockwise from the auxiliary rays. Also bc is an auxiliary ray drawn from b the position of which is correct. Set off the angle cbc' equal to θ and c' the intersection of the two lines $p'c'$ and bc' is the real plot of C; check by ac'. To find the position of c' geometrically it can be found as follows:—Since the angles $ac'x$ and acx are equal then c and c' are on the circumference of circle passing through the points $ac'cx$ and ac, cx and ax are chords. Find the centre of such a circle and describe it and where it cuts the line $p'c'$ is the true position of C as c'.

To find the true position of intersected points.—From the fictitious position c of C let a ray θ' be drawn to a temple, see fig. 77. This ray must first be transferred parallel to c' the true position of C and this can be done by a parallel slide on the sight rule. Let this ray be θ''. From the ray θ'' set off the angle θ clockwise and the ray $c'\theta$ will pass through the true position of the temple and its position is found by a true ray from p', intersecting it. The angle θ for correction of intersected points need not be projected by a sector if the artifice is adopted as recommended earlier for placing the table into azimuth.

In reconnaissance work and especially with an army on the line of march this method will be found exceedingly useful, first because cp is not measured and requires no measurement and on p being found and as at c the rays ca cb and cp are on the table (though p in the first instance was temporary) with the tracing paper method the rays ca cb and cp can be made to fit on a b and the true p and hence the true point c. Rays taken at c can be corrected accordingly, that is shots taken to other peaks, villages, &c., and hence there is no necessity to return to c. In figures 75 and 76 the distance apart of P and C relative to A and B has been shown to be much greater than it will actually be in the field. There would be no loss in accuracy if the distance P to C was $\frac{1}{8}$ the distance A to B as the fixing of P depends solely on the accuracy of the back and forward setting.

This graphical method is practically the same as Colonel Wahab's transfrontier triangulation method where the angles at P and C are measured. Note that the use of the compass is not necessary; it has been suggested here so as to keep the azimuthal error within reasonable bounds and so that the first intersection of c will be more or less correct, thus

preventing large shifts in rays for the subsequent adjustment of intersections.

175. **Planetabling methods—First method** — Having now treated of the theory of finding the position from two, three or more known points by interpolation or resection which in India is known as making a fixing or "a fixing" we may proceed with the first method of planetabling that is by magnetic compass and chain for direction and distance respectively. If the country is open, the compass of course can be dispensed with, but where the country is dense probably the method to be illustrated is the only one and has therefore its advantages. Take for instance a wooded valley or hill side where the features are hidden and where there is no certainty as to which stream joins which stream, &c., the only possible way is for the surveyor to "feel his way" through the under-growth and by crossing and recrossing detail to join up stream to stream, path to path. The portion of a map given (Fig. 78) conveys a good idea of such ground and is taken from the 4″ forest surveys of Burma. The ground is covered with dense under-growth of bamboo and cane and the surveyor was given the outer boundary as a theodolite traverse. The theodolite traverser left permanent marks 167, &c., for the use of the detail surveyor and also for forest purposes and he traversed in such a way as to give each detail surveyor a line, two to three miles apart, the lines if possible following some recognised administrative boundary or cleared forest fire lines. We will suppose that the dot and barred line was the given traverse and that it enclosed a block. To take this block as it stands and commence the detail survey from one corner and expand on it to the centre, &c., would end in disaster and in all such cases the surveyor must work from the whole to the part and not from the part to the whole, that is he should divide up the large block into smaller planetable traverse blocks.

With his magnetic compass unclamped and his sight rule set on a traverse station either to the back or fore when his table is over a traverse station, he finds his magnetic north and draws a line along the box of his compass. The chainman is sent to chain to a flag in a selected position and a ray is taken to the flag. The surveyor now takes up his table and proceeds to a position beyond the flag and sets up on magnetic north and the chainman chains from the flag to the table. The first measure is plotted along the ray already taken, and thus the position of the flag is known. Again a ray is taken from the plot of the position of the flag, and the second measure is plotted, this brings him to the position of the table. The surveyor continues in this way across his area following the line of least resistance from theodolite traverse to theodolite traverse. On the map let

such a line be represented by AB′A′. It will be found that such a line will have a certain amount of error but this error must remain unadjusted for the present. From B′ a suitable peg midway let a line B′B be run to meet the theodolite traverse at B.

We now have three lines which can be manipulated and adjusted BB′A, AB′A′, and BB′A′ and the mean or common point B′ can be pricked off, and its position will be as near an estimate of the true position of B′ as the circumstances will allow. If the block BB′A is first selected for detail work, some point C in BB′ could be selected and a line run to D and closed so that now we have a very much smaller block BCD in which we can proceed to fill in the detail by planetable traverse along the spurs and streams. Whatever error there is in the block BCD is confined to that block, &c. If the map contains sufficient margin of paper, any point may be taken to represent the theodolite traverse station and the traverse run out to the next theodolite traverse station across the blank piece of paper, the whole being traced off on tracing paper and adjusted and pricked through on the table in the true position of the traverse. This system for the main traverses such as AA′ and B′B is cleaner and there is only one set of holes and thus no confusion. Any detail, which it has been found impossible to survey, must be shown dotted (see map). The contour of such a map is pure eye contouring. In the map the height 940 is given as approximate, that is, it is probably correct to within 10 feet or so. This height has been deduced from flagged trees over traverse heights along the theodolite traverse and height values are entered only here and there in such maps, simply because heights in such ground are not greatly needed and to crowd a map with heights would lead to a wrong impression as to their accuracy.

The tangent clinometer is used to carry forward a system of heights station by station if the ground is fairly open and when this is not possible readings are taken as above noted to flagged trees. The general rise and fall of the ground is put in by angles of elevation and depression and the 0 line of the clinometer is made to sweep along detail opposite, to cut spurs, &c., at the same level approximately as the planetable's position.

It must not be taken for granted that flags are always visible. In dense undergrowth the surveyor will find that cutting a line will be almost impossible or would delay the work to such an extent as to make the cost of such a survey prohibitive. He will have to locate his direction on the sight rule by the glint of a looking glass, the waving of a branch and sometimes the sound of a drum. To the uninitiated in forest work, such methods will seem crude and exceedingly sketchy and yet these methods

have all been used and proved very successful. The beat of a drum with practice can be located to within a yard at 200 feet distance and this on the scale will have no appreciable effect on the ray. Long lengths of cane for measuring have been used on such work as it has been found that the ordinary surveyor's chain gets entangled and comes asunder.

The first setting of the compass is a very important operation and suitable long lines should be selected, and better still, from one traverse across to another. In the map suppose at A′ the planetable was set up and that a tree could be flagged very near A′. Its position being near could be fixed from A′ with an approximate magnetic direction. The planetabler next goes towards B and examines the ground between B and A; he will probably see the flag fixed at or near A′. He sets up his table to as near his magnetic north as possible over or near a traverse point and he measures and fixes his position. He now sets on A′ or the flag near A′ and thus obtains a very close approximation to the general magnetic north direction of the compass he will require in his work. He rules a line along the compass box edge and continues using this direction throughout his work. The greater the distance between the flag and planetable the more accurate the compass setting.

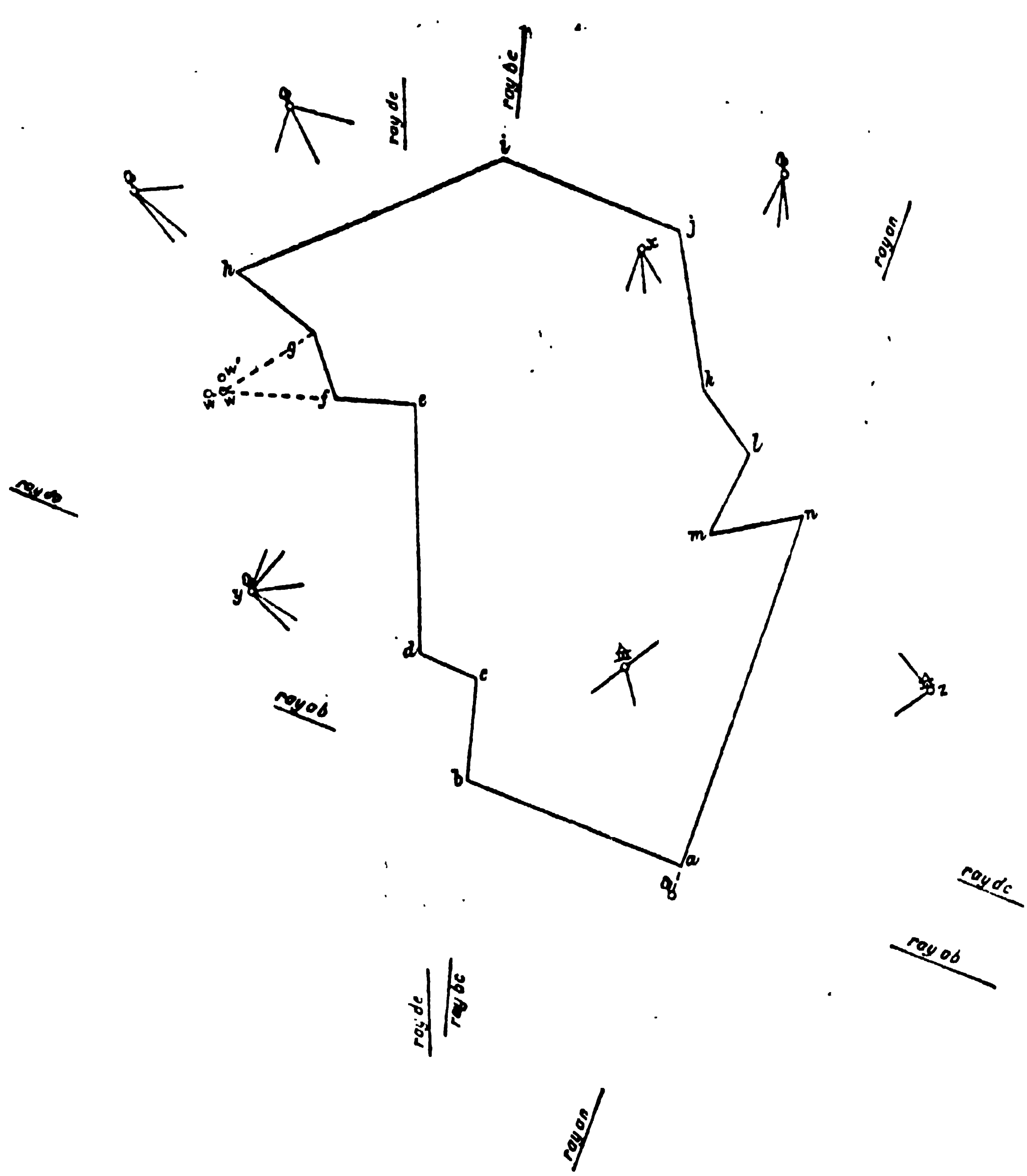
NOTE.—In the map all the theodolite traverse stations along the boundary are not shown but such stations as are permanently fixed on conspicuous points.

176. **Second method.**—If the country is open and there is neither a theodolite traverse or triangulation as a basis, a very accurate planetable traverse can be made by chaining with the **back and forward ray system,** see fig. 79. The direction of this traverse is in terms of the initial direction at the starting point and to obtain this a compass is used after which it is no longer required. Such a survey will not be geographically fixed, but will be useful in the mapping of small and outlying blocks of property, areas of grasslands and pasture. The scales vary from 4 to 16 inches to the mile. If carefully done the survey can be made extremely accurate and it is of course less costly than a survey on a theodolite basis. The illustration given will make the system clear.

Let *a* be any point representing a position A on the ground on or near the boundary; the point to be so placed on the paper as conveniently to take in the area needed.

At A the table is set up and turned into magnetic meridian by means of the compass. The compass is then put away. The flag men are sent

Fig. 79.



along the boundary to B and N and back and forward rays to B and N are taken and the rays produced and labelled as "ray *a n*," &c.

If there is a conspicuous back flag or tree near A it should be measured and fixed. The chainmen are set to measure the line A N and while they are thus engaged the planetabler takes rays to conspicuous objects, especially selecting such as will be useful to check his traverse later, e.g. *x y* and *z*. The table is now removed to N and the position of *n* plotted along the ray *an* by the measurement given. The plotted position *n* when the board is nearly correct in azimuth should be directly over the flag position of N. The sight rule is now placed along the ray *a n* and the ray *a n* produced and the point A intersected. The table will be again in azimuth with respect to the initial azimuth at A. The auxilliary points *x y* and *z* and

others are again shot to and the chainmen are sent to chain A to B and the table is removed to B and the same procedure gone through. As the positions of B and N have been fixed with reference to initial rays taken at A there should be no error in either B and N or in the points intersected from A B and N. If the points show an error in intersection then there is something wrong and these stations should be revised. The planetabler will thus see the reason for visiting N instead of continuing at once on to B, C, D, &c.

The work is continued to *c d e f* &c., and as it proceeds the rays taken to *y* for instance should all be passing exactly through the one point. Suppose at *f* or *g* a piece of high ground *w* is visited, that is chained to, and that back and forward rays are taken and the table is set up at *w* and that the conspicuous tree near *a* falls correctly on *w* but a ray taken from *x* falls away from *w* on to *w′*.

This would tend to show that the work is azimuthally correct but that the chainage is incorrect. On the other hand if *x* intersected but the prominent tree forced the ray from *w* to *w″* then the error is an azimuth error and not a chainage error. This check will show the extreme usefulness of intersected points.

By the time the planetabler has reached *i* he will find that the remaining positions of *j k l* and *m* can be fixed by the 3 point problem, and that the chain is no longer necessary. The boundary can now be inked up and the auxiliary points put in and all pencil work rubbed out; the paper cleaned and prepared for the detail work, such detail work being put in by chain and fixing or by intersection.

The following precautions are necessary for accuracy in such work :—(i) correct chaining, (ii) correct setting, (iii) a tested sight rule. The accuracy in chaining is understood, as on it depends the distance from point to point. The correct setting is necessary as the board must occupy a position from the back position in exact relation as the flag at the fore position had to the table in the back position, so that on large scales when the table is in azimuth the plotted point should be exactly over the point *in situ*. As regards the sight rule it is essential that the line of sight should be parallel to the fiducial edge of the ruler, and that the sight rule should show no difference for a line drawn one way and then the other, that is, when the observation vane is one direction and then the rule is turned end for end (see para. 160.) Inaccuracy in the sight rule enters especially in the back and forward ray work and the surveyor who understands the collimation error in a theodolite will see the reason for this.

Heights for this class of survey are found with the tangent clinometer accepting any datum for A if no given height is forthcoming. The heights of N, B, C, &c., are found by reciprocal observations and heights are given to intersected points and they will check *inter se* the heights of the stations.

The method is quick, useful and very accurate and as much as a seven mile perimetre can be done in a working day.

177. **Third method.**—The following paragraphs will embody hints instructions and notes on the use of the planetable as a topographer's ideal instrument. Based on a theodolite traverse or triangulated points no other instrument can compete with it as an accurate detail filler for the following reasons:—Any error is confined solely to the fixing from which the work was done and there need be no error as no fixing should be incorrect for reasons given hereafter. The planetable permits of the surveyor at all vantage points checking his own work and if there is, in his detail a disagreement, then either some of his detail is incorrect or his fixing is faulty or at any rate, is not in terms with work from some other fixing. Its facility in finding position by interpolation. Its rapidity in furnishing auxiliary points also intersection of detail. It dispenses with field notes, hence no mistakes in plotting. It delineates the ground as seen by the surveyor who is not expected to trust to his memory and a note book. An inaccessible range can be cut in from three positions. The surveyor is not tied down to a chain though it will be shown that the chain is very often, on certain scales, a very useful adjunct. The scope it gives the surveyor in that it permits him to discriminate between necessary and unnecessary detail with reference to the scale on which he is working. Its disadvantage is possibly its weight and its liability to weather changes when the wood used expands and contracts and the map is distorted so that the plottings of the points become "skewed" and inaccurate.

Let it be supposed that a table has been mounted and thoroughly dried. The next operation is the plotting of the points either by rectangular co-ordinates or by latitudes and longitudes. For the former convenient squares should be accurately ruled * and for the latter proper graticules should be projected and ruled, the ruling being carefully done in blue ink when they have been tested for diagonals, &c. These squares or graticules are extremely useful for plainmeter check areas (see plainmeter, para. 94).

The data given are plotted, checked and inked in circles; the size of circles being proportionate to the accuracy and importance of the given

* A graticule plate is a very quick method for pricking off a rectangle divided into inches.

values, e.g. theodolite stations or positions at which the theodolite was set up should have larger circles than theodolite intersected points and again smaller circles to denote planetable intersected points. These circles may be put in carmine.

The planetable is set up as a start on a theodolite station and since, for most small scales the whole planetable in plan is a dot no great accuracy of exact setting over the point *in situ* is necessary. The planetabler puts on his magnetic compass to obtain a rough azimuth and with his sight rule parallel to the plots of the station over which he is standing and another station he examines the line of sight and probably finds the exact alignment by a slight orientation. The compass can now be corrected to a line drawn along its edge or the variation noted, when it is put away. The points, as given, are now thoroughly examined, and if an error is found in a theodolite intersected point of single value (which has been deduced and given as being possibly correct) the point should, if found to fall off the ray of the sight rule, be refixed with the aid of the planetable. The setting of the table for azimuth must be on the most distant point available for the reason that the setting will be truer. Having recognised and committed to memory the given points, the planetabler should select and cut in all easily recognisable objects, such as prominent or curious trees (that is trees of a different colour to the rest or trees with a bare sprig on the top) chimneys, spires, temples, pagodas and clinometer readings should be taken and written along such rays. The setting should be again checked to see that the table has not moved during these operations. Rays should be drawn with a fine pointed pencil held at an angle with the fiducial edge corresponding to the angle which the pencil makes at the plotted point or position over which the table is set. Where necessary a sketch of the point or object intersected should be made as an aid to memory. Experienced surveyors use very hard pencils which they continually bring to a fine point and have abbreviations such as s, l, g, t. for spur, light, green tree, h, t, f. for hill, tree, flag and they are capable of drawing a ray and putting a circle on the ray to within a ¼″ of the real position. To be able to do this is due to the eye being in time trained to judge distances fairly accurately.

The beginner will have to satisfy himself with long rays and long descriptions and the subsequent rejection of probably more than half of the shots taken, mainly because experience has not taught him that objects conspicuous from one position may be hidden entirely from another. If there were more than one chimney or palm tree situated together they should either all be cut in or left severely alone.

The planetabler has now got so far that he has recognised most, if not all his trigonometrical points and by his most distant setting he has obtained his magnetic direction and has drawn rays to points he requires to supplement the triangulation and he has taken clinometer readings to a number of such. He should now set up at another theodolite station, retest and cut in, but before arriving there it is good plan to set up his table on some conspicuous place not very far from his last and obtain a fixing from which he can shoot in a number of his auxiliary points and obtain very good approximations of their positions. The fixing from which these rays are taken may not be absolutely exact, but it will serve its purpose in so far as it will enable the beginner at any rate to subsequently pick up many points which he might otherwise certainly have confused or lost.

At the second trigonometrical station the planetabler again sets on his most distant point and proceeds to check all the given data and to cut in his own auxiliary points giving them clinometer values.

A third point is visited which need not now necessarily be a theodolite station but may be a theodolite intersected point or if he is sure that he can make certain of several given points and he is within the triangle of such points he might make a fixing. The third set up should be well selected so that the rays to auxiliary points will make good cross intersections with the previous two rays taken. The condition of these rays and the quality of the intersection will determine as to whether the point can be accepted or whether a fourth ray is necessary.

It has been noticed that one of the disadvantages of the planetable is its propensity to warp, that is, in a rectangular board owing to the grain of the wood being lengthwise when the contraction and expansion is breadthwise, the points become "skewed" and the following precaution should be deemed necessary. The planetabler should in the first few days cover his area with auxiliary points and visit all his stations in doing so. If the area, according to the scale, precludes him from doing his it would be better for him to take up only a portion on one table and that he projects and cuts in points for the remainder on another board. He will be able to tell whether his points are accordant or not by fixing with one set of points and setting on a distant one and then checking others which are also distant. If the shift is very little the error in the fixing may be inappreciable but with a new board or a board which has yet to settle down to climatic conditions, as much as ¼″ contraction in the graticule has been noticed, and it is for this reason that the experienced planetabler

will in preference select an old and acclimatised board or table so long as its surface is flat and regular. It is a good system to weather boards in the climate in which they are to be used and in mounting planetables the paper only should be wetted as has been already advised.

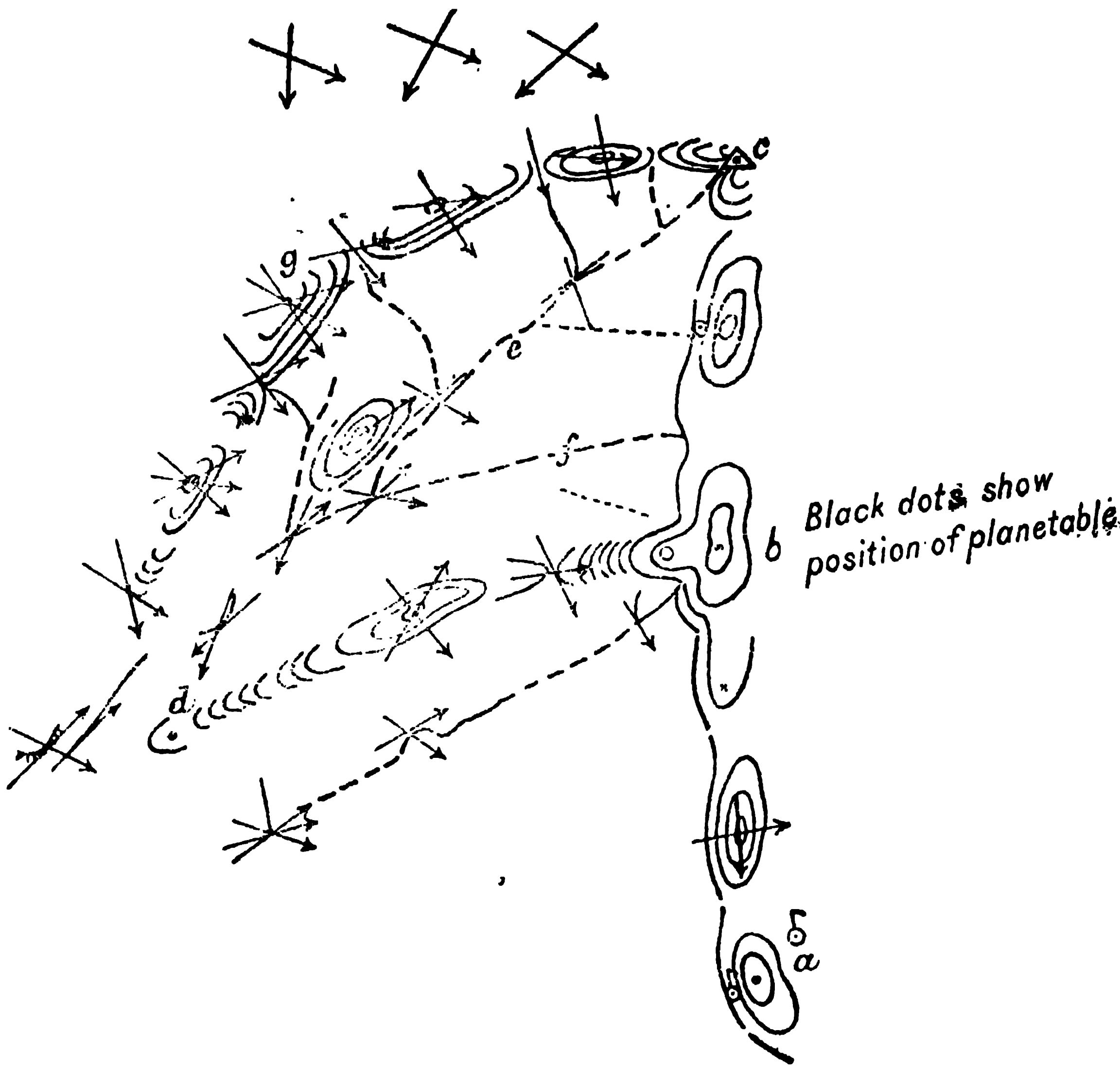
This slight digression will, it is hoped, prove to the novice the advisability of first spending a few days going over his ground instead of starting at once on detail work. The question of working from the whole to the part must be reiterated as it is one of the most important of survey maxims. Further it must not be thought that all boards "give" and points are slewed, and it must not be taken for granted, if trigonometrical or other well fixed points show an error, that the point is wrong and not the fixing.

The planetabler must accept his given data without question, that is double value data, and the object of fixing numerous auxiliary data is to avoid any suspicion of doubt and to make the work accord. The planetabler will use his near points to fix by and any contraction or expansion in the map will mean that the error will be evenly distributed and the photography and mapping will correct it when the field work is again drawn and adjusted to true graticules.

Auxiliary points should be thrown out beyond the area of survey to avoid the fixing without the triangle (see para. 173) and the planetabler, who rigidly confines himself to points in his area only, will find that any error in his marginal or overlap work is due to his slackness or want of a little extra trouble and foresight.

178. To resume—the table now being complete with data so that the surveyor can fix, that is, see at least three fixed positions in any open clear spot, he should first take up the watershed or highest ground and preferably a high ridge lying between two others and work down to the valleys and spurs. Consider the skeleton survey illustrated (Fig. 80.) Let *a* be the first fixing. If the illustration is examined (only one side of the ridge is shown) the rays with arrow heads show what shots were taken—such shots are to hill tops, saddles, spurs, bends and junctions of streams; heights are read to the most important of these as an aid to contouring. As it is possible that even if *a* is flagged or brushed the point will not be seen down in the valley, and it is quite possible that a fixing will be required in the low ground, on each side two overhanging trees are chosen, brushed, and measured to. These points are shown in small circles. The next position will perhaps be *b* or even an intermediate one (shown by a small cross). At *b* the planetabler fixes up and again takes shots and cuts in and

Fig 80.



sketches along the ray all streams running directly in a line towards him. At *c* which happens to be a trigonometrical point he continues his cutting in and spends a little time in working out his clinometer heights and so sketches in a few of the hill tops down to the saddles, &c. We will suppose he now finds that although he has the ridge contoured he has only a small portion of the main stream sketched and that *d* will make a good position for cross intersections and also for a lower and better view up the valley. If he thinks that the chances at *d* are, that he will not see points to fix by, he provides for such before visiting *d*.

At *d* he continues work but finds that the portions marked *e* and *f* are still unsurveyed so he goes down into the valley and with the points at his disposal and which he had the foresight to see would be necessary, he fixes and puts in correctly all the bends and junctions which could not be seen from the high ground. The method of flagging or brushing overhanging trees as a temporary measure is an exceedingly useful one and makes fixing in the low ground easy and this very fact induces the surveyor to fix at or

near such detail instead of trusting to cut it in from the surrounding high ground, from which it is quite possible some important feature is hidden and omitted. Out crops of rock on the hill side should be cut in, and even if the position of such is slightly inaccurate, the height taken to it would not be so, and such a height would be a great aid to contouring. At *d* having obtained the height of the planetable and the "0" level of the clinometer which could be twisted in all directions and a guide to that level could be marked in as going just at, above or just below a certain bend or junction of a stream. As a test now of the work done the planetable can be taken to *g* and the work examined and the next area to be surveyed shot in &c.; in fact the work, as it progresses, should be repeatedly examined when the planetabler has time and this often occurs during the intervals the chainmen are making measurements to flags and edges of cliff, &c. These are golden opportunities and should never be lost. Before quitting a fixing, the surveyor should thoroughly satisfy himself that he has done everything he intended doing and there is nothing left for him to do. One so often sees the planetable lifted and carried 20 yards and returned reset, &c., because it has just struck the surveyor that an important ray which he intended taking has been forgotten. There is no excuse for the surveyor returning time after time to the same fixing or for the surveyor who stands by his table and expects his squad to investigate this, that and the other. This usually means loss of time and consequently money and a great deal of unnecessary shouting. The man who brings in the best work is the man who personally inspects the ground he is surveying leaving nothing to his men to discover, which he himself does not know already. Planetabling demands at the time the whole of the surveyor's intelligence and attention and concentration of the mind is one of quickest and surest ways to get on with the work. Nothing should be left to chance and everything must be most accurate. To start well is to end well.

179. (*a*) In a previous paragraph the rule to fix by your nearest points and set on your most distant has been quoted. The rule is obvious as the closer the cutting in, the less the shift of your point in the triangle of error and the longer the setting the more correct the azimuth will be. It must be recollected that, although three known points will give the fixing, a fourth point should also be intersected to place the fixing beyond any doubt. As regards the fixing without the triangle comment has already been made, but it must be added that surveyors in India will probably planetable thousands of fixings a year without having recourse to a fixing without the triangle and so the avoidance of such a fixing cannot be such a difficult matter.

(*b*) A few additional hints and short cuts will not be out of place here. One frequently hears the expression " a surveyor should not be tied to the end of his chain." Quite so, but the chain, as has been remarked, is a useful adjunct and on the larger scales of 16″ 8″ and 4 ″ to a mile its use has one great advantage, viz. celerity of fixing.

The method of planetabling with the chain in fairly open and flat country is as follows:—Having set up the table and obtained a fixing we will suppose it necessary to descend into a stream say 300 yards distant. While the surveyor is engaged taking rays, &c., the chainmen are chaining a line on any direction which the surveyor has found will bring the chainmen into a suitable position near the stream. The chainmen are directed to halt when they come to the stream and to leave the chain on the ground stretched to the last measure.

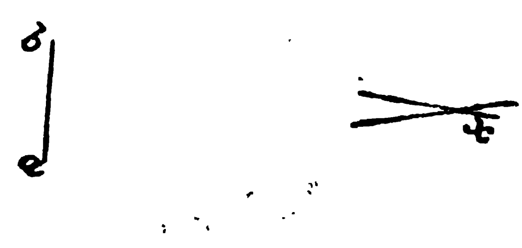
As soon as the surveyor has completed his work at the fixing he proceeds to his chainmen. The chain measure, with the ray taken for direction, will give him the position but he will require one other point to orientate his board on. He therefore moves along his chain till he sees a distant point, the further the better, and sets up his table at that position over the chain. He takes off his measure and plots it and sets his board. If his previous ray had been correct and also the measure, and there is no reason why they should not be, he will find no error in the plot, but to make certain it is possible by looking around he will see some other point to test by. If such a point is not at once visible by putting his sight rule on the point over which his table is set and the plot of the other he will probably by the aid of field glasses see the flag or brush he is searching for. If he had not measured the distance he would not have been able to do this and his search would have been in vain. However let us suppose he obtains no check point at this station but accepts it. He proceeds to put in the detail near him and starts the chainmen in another convenient direction up or down the stream taking a ray on to any good mark such as a tree, rock or bush, and noting that the chainmen are keeping to the line. He follows the chain making, for small scales, rough notes of cuttings and offsets by pacing perhaps, and halts when he thinks he has proceeded far enough and when he can see a point to set on and also a point from which he will obtain a cross ray. This he does by plotting his position on the ray from the last station setting his position on to a distant point and testing by another point. If there is no error the point becomes a fixing from three rays, if there is an error, provided the chaining has been good, it will be small and due to inequalities of the

ground and can if necessary for the scale be distributed. The advantage of this is that the chain measure enabled the surveyor to set up at a position which he could not have found by interpolation, and further that the chain being dragged up or down the stream permitted him to put in all the bends and other detail from close quarters. Thus the planetable traverse by a distant point for azimuth is a valuable means of saving time; looking for fixings and finding them where they are not always necessary cannot be considered a superior method to the above. It is always advisable to be as near the detail to be surveyed as is possible, and this is very often only practicable by means of this method. To sum up the various advantages they may be said to be as follows:— It is superior to any of the other planetable traverse methods and the plot is found by measure, reduced if necessary, to the horizontal. Even if three points are visible it is a very quick way to find the fixing as the true azimuth of the board is obtained at one setting instead of two or more, and it permits of the table being placed for detail in positions where a fixing would be impossible—its error, if any, can always be checked and distributed by continuing the traverse on to a point where a fixing is possible, and thus closing it and lastly it is an easy and quick method of putting in a certain class of detail such as a road, path or stream.

(c) The next short cut is often employed on transfrontier work, see fig. 81, and is often useful in fixing a point by two intersections only when the rays are acute.

Let a and b be two points on the table from which rays to x have been taken. The position of x may be said to be approximate as regards its distance from a and b, so that if it is possible to plot a and b to a large scale say four times and to intersect x and then to quarter the distance ax or both and to plot this distance from a or b or both, then the position of x will be much more accurate.

Fig. 81.



The expanding of ab to 2, 4 6 or 8 times its distance can be done on any part of the table and a back and forward ray may be the ray ab produced. The point x is interested from both the true a and b and the expanded a and b. The expanded distance ab may be either so many

times the distance between the fixings a and b or better still the chain measure ab plotted to a suitable larger scale.

(*d*) Another artifice is as follows:—At some position in which a fixing is required two points can be seen but a third is hidden by a line of trees, a bank or a low range of hills. This frequently happens and the third point is seen only by moving perhaps a 100 yards from the table in a contrary direction to the point from the table, that is the point is visible over the line of trees and the planetable lies between.

First set up the table where two points can be seen and with the magnetic compass obtain, with two rays, an approximate position. Now set the position just found and the plot of the invisible point along the edge of the sight rule, just as if a ray was being taken from the point had it been visible. The sight rule is left in this position and the surveyor takes a flag and from the position at which the required point can be seen, he aligns the flag, sight rule and point and leaves the flag in position. He returns to the table and shoots in the flag from the plot of the third point, draws his ray backwards and thus obtains the third ray. The accuracy of this method depends on the aligning of the flag, sight rule and point and the further the flag is away from the table the greater the accuracy of the ray. The fixing from two inaccessible points has been given in an earlier paragraph (174) and is perhaps of greater use to the reconnaissance surveyor or the intelligence officer attached to a force on the line of march.

180. **Contouring.**—Rigorous methods will not be touched on in this chapter as the tangent clinometer cannot be considered to be a precise instrument, but such as it is, it is admirably adapted for the purpose for which it is used, that of obtaining heights to within five feet at a distance of two to three miles and eye contouring by interpolation between such heights. The height of the table is deduced as follows. The clinometer is levelled and say a point is read and the reading on the natural tangent scale is ·012 the distance being scaled is found to be 10,000 feet from the fixing to the point; the difference of height$=10{,}000\times{}\cdot012=120$ feet to which the correction for curvature and refraction must be applied; a second reading is taken to another point the height of which is known and the mean of the resulting values will be the height of the instrument at the table required from which must be subtracted four feet to obtain the value of the ground level beneath the table.

The rise or fall of ground and its slope can be read and the position of the next contour fixed, and if the slope of the ground is even, additional contours at certain height intervals can be put down by plotting the

horizontal distance. A rough rule is as follows:—As degrees and quarter degrees can be read on the left hand side of the vane a fall of 1 foot for $\frac{1}{2}^\circ$=114·6 feet horizontal or 115 feet roughly; for 1°, 57·3 feet; for 5°, 11·46 feet, or $\frac{1}{10}$th of the distance for $\frac{1}{2}^\circ$.

If the height at the table *in situ* is 1,021 feet and if the contours are at 25 feet interval then with a slope of 5° read to an imaginary plane four feet above the ground the 1,000 feet contour will be (1,021—1,000) × 11·46 or 240·6 feet and to obtain the 1,025 foot contour the horizontal distance will be (1,025—1,000) × 11·46=~~45·8~~ 286·5 feet. If the surveyor has a scale of slopes and the slope is even he can put down from his scale successive contours down the slope.

If two heights are given or found and the surveyor is required to interpolate contours, a simple device for putting down the requisite number at even intervals, is as follows:—Take two pieces of wood joined together by two brackets exactly as for the ivory parallel ruler supplied in instrument boxes. Bore holes at equal and given intervals on the inner edges of the rules and thread them through so that you will have when the brackets are fully extended a system of parallel threads at right angles to the rules.

If 20 contours are required between two heights 20 threads are made, by moving the rulers slantwise, to fill up the interval. Each thread is then ticked off (see Engineering news, July 30, 1903).

The use of the clinometer to trace out a level line has already been touched upon.

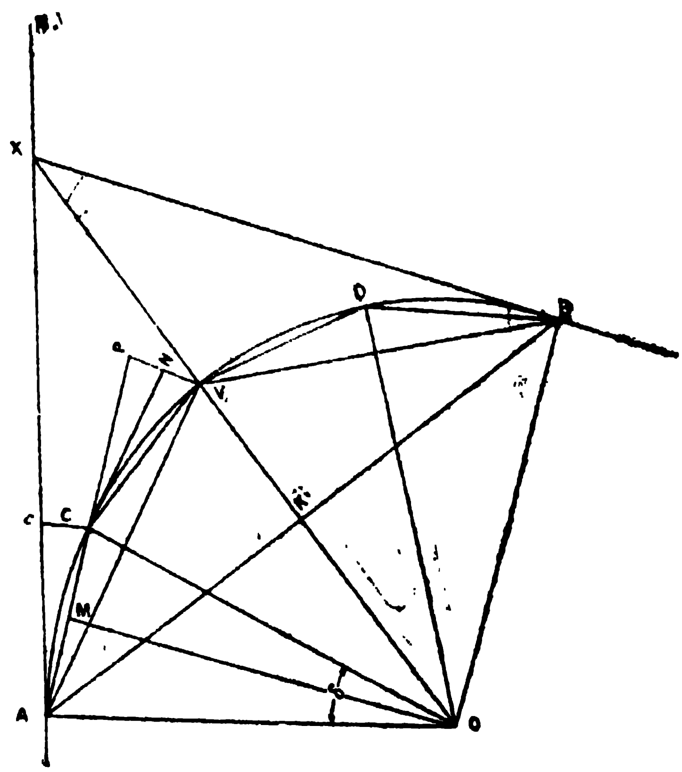
To save a deal of trouble in using the clinometer and for reasons of the sight rule when the thread stretched from the vanes is used for very high and low objects, a small circular or an ordinary carpenter's level should be carried for levelment of the table. When the table is level or nearly level the clinometer is quickly levelled and the vanes are thus very nearly perpendicular, and hence the heights are nearer the truth (see fig. 67).

CHAPTER VIII.

CURVES.

181. Railway curves are mostly circular curves, though parabolic curves are sometimes used. In curves the directions of the two pieces of straight or tangents are known, that is AX and BX (see fig. 82) and therefore the angle AXO or half the angle AXB is constant and AX varies as AO or if a given radius is accepted then the tangent points (TP[s]) A and B are fixed and again if AX and BX are accepted or given, then the radius AO is fixed.

Fig. 82.



A curve is defined (Method I) by length of its *radius* in feet or links or (Method II) by its degree of curvature in degrees, minutes and seconds. In ordinary practice ½ minute will be found sufficiently accurate.

Method I is the usual method in England and Method II is almost exclusively employed in America and India and under most circumstances is probably to be preferred to the radius system, and this system or the degree system, will be treated of in this chapter.

A circle with a radius of 5,730 feet will have a circumference of 36,000 feet and it will be seen that a 100 foot chord will thus subtend 1° at the centre and in the degree system the usual length of chord is 100 feet and hence the angle, which such a chord subtends at the centre, is known as the curvature or (δ). If in figure 82 AC, CV, VD, DB each happened to be 100 feet in length and the curvature δ be 1° then the angle through which the curve has been turned from TP to TP would be 4° or the angle AOB.

182. **Circular curves** may be classified as **simple** and **compound.** **A simple curve** may be defined as a single circular curve connecting two lengths of straight meeting at an angle; **compound curves,** where a curve of one radius runs into another of different radius but of similar flexure, or where a curve of one flexure runs into another of different flexure, sometimes known as a **serpentine** curve.

The curve of deviation or diversion curve is a double compound curve and is one which starts from the straight and returns to the same straight again.

It is always necessary to have a piece of straight between the TP of one curve and the TP of another curve to allow for the change in superelevation of the outer over the inner rail. A gradual change from the straight to the curve can be introduced by means of the **Transition** curve. The curve as laid down is always the centre line between the rails.

183. Some of the properties of the circle may now be examined. In fig. 82 AX and XB are two tangents intersecting at X and touching the circle at A and B.

If from A and B two straight lines are drawn at right angles to AX and BX they will intersect at O the centre of the circle and AO and BO will be radii of the circle. If X and O are joined XO will cut the circle at V then the arc AV will equal the arc BV, the angle AOV will equal the angle BOV. If A is joined to V and B is joined to V then AV will bisect the angle XAB and BV will bisect the angle XBA.

Since the triangles XBK and XBO are similar, that is that the angle XBK is equal to the angle XOB therefore the angle AOB is twice the angle XAB or twice the angle XBA.

184. **Definitions.**—The angle AOB is known as the *central* angle (β) and is subtended by the *long chord* (C) or the straight line joining the tangent points A and B. A is the TP or tangent point where the curve commences and B is the TP or the tangent point where the curve ends. The angle AXB is the *intersection angle* (θ) and is the supplement of the central angle or $\beta = 180 - \theta$.

Tangential angle is the angle contained between a tangent at any point and the next chord of 100 feet. If AC be that chord then XAC is the *tangential angle,* and the angle at the TP between the tangent and the long chord is defined as the *whole tangential angle* (γ) and this has been shown to be equal to half the central angle that is $\gamma = \frac{\beta}{2}$.

Deflection angle is the angle between a chord produced and the next chord or if CV is the next chord the angle PCV is the *deflection angle.* The *whole deflection angle* is the angle through which the curve is turned

or the angle RXB and is equal to the central angle or is the supplement of the intersection angle and is thus double of the whole tangential angle. Similarly the deflection angle PCV is double the tangential angle XAC.

185. **Degree of curve** *in terms of the radius (R)* (see fig. 82).

Let AC=100′ chord= c and if OM bisects the angle AOC then $\frac{AM}{R} = \sin\frac{\delta}{2}$ and since AM = MC = 50 feet then $R = \frac{50}{\sin\frac{\delta}{2}}$

Example.—Find the radius for a 12° curve.

Here $R = \frac{50}{\sin 6^\circ} = \frac{50}{\cdot 10453} = 478\cdot 3$.

Length of the tangents (T) *in terms of the radius R, the whole tangential angle (γ) and the angle of intersection (θ).*

AX = OA tan AOX.

$\therefore T = R \tan\frac{\beta}{2} = R \tan\gamma = R \cot\frac{\theta}{2}$.

Example.—Find the length of the tangent for a 2° curve containing an angle of 30°·15′.

Here the angle at the centre or central angle is 30°·15′ and $R = \frac{50}{\sin\frac{\delta}{2}}$

$= \frac{50}{\sin 1^\circ} = 2864\cdot 9$ feet.

And $T = R \tan\frac{\beta}{2} = 2{,}864\cdot 9 \times \tan 15^\circ\cdot 7\frac{1}{2}'$.

$= 2{,}864\cdot 9 \times \cdot 27029$.

$= 774\cdot 4$ feet.

Length of the curve (L) measured along the chords. If β = central angle and δ the degree of curvature then $\delta : \beta :: 100 : L \therefore L = 100\frac{\beta}{\delta}$ feet.

Example.—Find the length of a 2° curve containing an angle of 30°·15′

Here $L = \frac{100 \times 30\cdot 25}{2} = 1512\cdot 5$ feet.

Length of the **long chord** *(C).*

Here $C = AB = 2\,AK$, and $\frac{AK}{R} = \sin\frac{\beta}{2}$.

$\therefore C = 2\,R \sin\gamma$.

Example.—Find the length of the long chord C for a 2° curve containing an angle of 30°·15′.

Here $R = 2{,}864\cdot 9$ (see example above).

And $C = 2\,R \sin\gamma = 2\,R \sin 15^\circ\cdot 7\frac{1}{2}'$.

$= 2 \times 2864\cdot 9 \times \cdot 26093$.

$= 1495\cdot 1$ feet.

The **middle ordinate** *(V).* Join AB and let AB intersect OX in K.

The middle ordinate $KV = VO - KO = R - KO = R - R\cos\gamma$.

$$\therefore\ V = R(1-\cos\gamma) = R \text{ versin } \gamma.$$

Or by geometry $AK \times KB = VK \times KN$ (N being a point on the circumference in VO produced).

$$VK = \frac{AK \times KB}{KN}$$

$$= \frac{\frac{C}{2} \times \frac{C}{2}}{KN} = \frac{\frac{C^2}{4}}{KN}$$

Now if VK is very small KN may be considered almost equal to the diameter of the circle or 2 R.

$$\therefore\ VK = \frac{C2}{8R} \text{(approx.)}$$ see also para. 193.

Example.—Find the middle ordinate for a 2° curve with a central angle of 30°·15′.

$$V = R \text{ versin } \gamma = 2864{\cdot}9 \text{ versin } 15°{\cdot}7\tfrac{1}{2}'.$$
$$= 2864{\cdot}9 \times {\cdot}03464 = 99{\cdot}2'.$$

To find the centre point of the curve by measurement from the intersection point of the tangents, i.e. to find the **apex distance.**

$$OX = OV + VX.$$

$$\text{Apex distance} = VX = OX - OV = OX - R.$$
$$= R \sec\frac{\beta}{2} - R = R(\sec\gamma - 1)$$
$$\text{or } R\left(\text{cosec}\frac{\theta}{2} - 1\right).$$

Example.—Find the apex distance of a 2° curve with a central angle of 30°·15′.

$$\text{Apex distance} = R(\sec 15°{\cdot}7\tfrac{1}{2}' - 1).$$
$$= 2864{\cdot}9\left(\frac{1}{\text{Cos. } 15°{\cdot}7\frac{1}{2}'} - 1\right).$$
$$= 2864{\cdot}9\left(\frac{1}{{\cdot}96535} - 1\right).$$
$$= 102{\cdot}8 \text{ feet.}$$

Example on the above formulæ.

Two straight lines meeting at a known angle θ are to be joined by a 2° curve. Describe the computations and the method of lining out the curve in 100 feet lengths (I. C. E. 1910).

The supplement of the intersection angle θ = central angle β through which the curve is to be turned$=180-\theta$.

(ii) $R = \dfrac{50}{\sin\frac{\delta}{2}} = \dfrac{50}{\sin 1°} = \dfrac{50}{{\cdot}01745} = 2864{\cdot}9.$

(iii) $T = R\tan\frac{\beta}{2} = 2864{\cdot}9 \tan\frac{\beta}{2}.$

(iv) $L = \frac{100 \times \beta}{\delta}$.

(v) $C = 2R \sin\frac{\beta}{2} = 2 \times 2{,}864 \cdot 9 \sin\frac{\beta}{2}$.

(vi) Apex distance $= R(\sec\frac{\beta}{2} - 1) = 2864 \cdot 9\ (\sec\frac{\beta}{2} - 1)$

(vii) $V = R \text{ vers } \frac{\beta}{2} = R \text{ vers } \gamma = 2864 \cdot 9 \text{ vers } \gamma$.

(viii) The tangential offset $= \left(\frac{\text{Chord}}{2R}\right)^2$ and deflection offset$=\left(\frac{\text{Chord}}{R}\right)^2$ (see para 189).

(ix) The length of any ordinate O measured from the long chord C $= \sqrt{R^2 - X^2} - (R - V)$; this formula will be explained later (see para 189).

186. In a previous para it has been laid down that a chord of 100 feet will subtend an angle δ at the centre and this system is used in most books since the measurements made in laying out the curve are along the chords. The Government of India rules for the preparation of railway projects, Chapter III, paragraph 2, lays down that it is easier to accept the arc and not the chord and it has this advantage that having calculated the value of the radius of a curve of 1°, the corresponding value for a curve of any degree δ is obtained at once by simply dividing by δ.

For example, the radius of a 1° curve is $\frac{100}{\cdot 0175433} = 5729 \cdot 58$ or more accurately $5729 \cdot 57795$ the logarithm of which is $3 \cdot 7581226$, and the radius of a 12° curve will be $\frac{5729 \cdot 58}{12} = 477 \cdot 46$ (compare previous result); and T the length of the tangent will be $\frac{5729 \cdot 58 \times \tan \gamma}{\delta}$, and if $\gamma = 15° \cdot 7\frac{1}{2}'$ and $\delta = 2°$ then $T = \frac{5729 \cdot 58 \times \tan\ 15° \cdot 7\frac{1}{2}'}{2} = \frac{5729 \cdot 58 \times \cdot 1249997}{2} = 774 \cdot 32$ (compare previous result); and similarly the apex distance will be $= \frac{5729 \cdot 58\ (\text{Sec.}\ \gamma - 1)}{\delta}$.

The difference in the results between the two systems is not appreciable for small degrees of curvature, but when it is remembered that standard dimensions allow of curves of 16° on the metre gauge and 48° on the 2 '6" gauge then the differences would be fairly large.

The error in taking the chord as equal in length to the arc is $\frac{\text{Arc—chord}}{\text{arc}}$ and if β is the central angle then $R\ \beta$ is the length of the arc and $2R \sin\frac{\beta}{2}$ the length of the chord and the error will be

$$\frac{\beta - 2\left\{\frac{\beta}{2} - \frac{\beta^3}{48} + \text{etc.}\right\}}{\beta} = \frac{\beta^2}{24}.$$

If the ratio $\frac{\text{chord}}{\text{radius}}$ does not exceed $\frac{1}{10}$, the error will be less than ·0041 i. e. about $\frac{1}{2400}$; if the ratio $\frac{\text{chord}}{\text{radius}}$ does not exceed $\frac{1}{20}$, the error will be less than $\frac{1}{10,000}$. The following lengths of chord are recommended in setting out curves of different curvatures.

For curves of 0° to 5° set out with 100′ chords.

. . . . . 5° to 10° . . . 50′ . . .

. . . . . 10° to 20°. . . . 25′ . . .

Simple curves.

187. METHOD I.—**Setting out a curve with a 100′ chain and a theodolite.**

Example.—Intersection point occurred at station 753 + 34. Angle between tangents was found to be 142°. Put in a 5° curve.

Here δ and θ are given, hence R $\frac{50}{\text{Sin } 2\frac{1}{2}^\circ}$ = 1,146·3 and T = R tan γ = 1146·3 × tan 19° = 394·7 (approximate). Chainage at the commencement of the curve or the first T. P. is 394·7 feet back from X the intersection point = (753+34)−(3+94·7) = 749+39·3.

$L = \frac{38^\circ}{5^\circ} \times 100 = 760$ feet $= 7+60'$.

Therefore the chainage at the end of the curve = (749+39·3) + (7+60) = (755 +99·3) and chainage to the vertex V =(749+39·3)+ $\frac{(7+60)}{2}$ =(753+19·3).

Apex distance=R (sec $\frac{\beta}{2}$—1)=1146·28 (sec 19°—1).

=66 feet nearly.

C=2 R sin γ=2×1146·28×sin 19°=746·38′.

V= R vers 19°=62·47′.

It is supposed that the surveyor or engineer chained up to the intersection point, registered the value of the chainage, set up his theodolite and after reconnoitring the ground found that the angle between the tangents is 142°. He now either decides the TPs. by the length of the tangent or in this case the curvature δ=5°.

He computes the apex distance to be 66′ to the vertex of the curve which he proceeds to fix by means of a measure of 66′ and the bisection of the intersection angle. He puts in a peg here and labels it vertex with a chainage of 753+19·3.

His work at the intersection point is completed and he proceeds to measure 394·7′ along the tangents and fixes pegs to denote the TPs. or commencement and end of his curve. The chainage at the commencement

curve will be 749+39·3 and the chainage at the end of the curve will be 756+99·3.

The theodolite is now centred over the first T. P. peg at chainage 749 +39·3. The instrument is levelled and the plates set to 0° 0′ 0″; the lower plate is now unclamped and the telescope set on the intersection point and the lower plate clamped when the peg is intersected. The upper plate is now released and the following checks made to ensure of the initial work being correct. The vertex peg should read an angle of 9°·30′ $\left(\frac{\gamma}{2}\right)$ and the other T. P. peg should read 19° (γ). This is assuming that the curve is a right handed one; if a left handed one these values should be subtracted from 360°.

These checks having been made the curve can be proceeded with and the pegs marking the different stations on the curve will mark the *centre line* of the track or canal, &c.

In order to obtain the 750th peg which is 60·7′ distant from the position of the theodolite the tape or chain is stretched to 60·7′ in a direction which on the theodolite (A vernier usually) will read 1° ·31′ ·0″. This is found as follows :– Since the degree of curvature is 5° the tangential angle for each 100′=2° ·30′.

∴ the tangential angle for $60{\cdot}7' = \frac{60{\cdot}7}{100} \times 2\frac{1}{2}° = 1° \cdot 31' \cdot 03''$. The 751st peg will be put in with an angle of 1° ·31′+2° ·30′=4° ·01′ and the chain or tape stretched 100′ from the 750th peg into this line and so on. In using a chain with the tape they must be compared against each other. The chain again is not necessarily correct throughout its whole length if its total length is correct (see paragraph 20). The curve will be checked at the vertex by a distance of 19·3′ from the 753rd peg with an angle of 9° 30′ and the last peg should measure 99·3′ from the 756th peg with an angle of 19°.

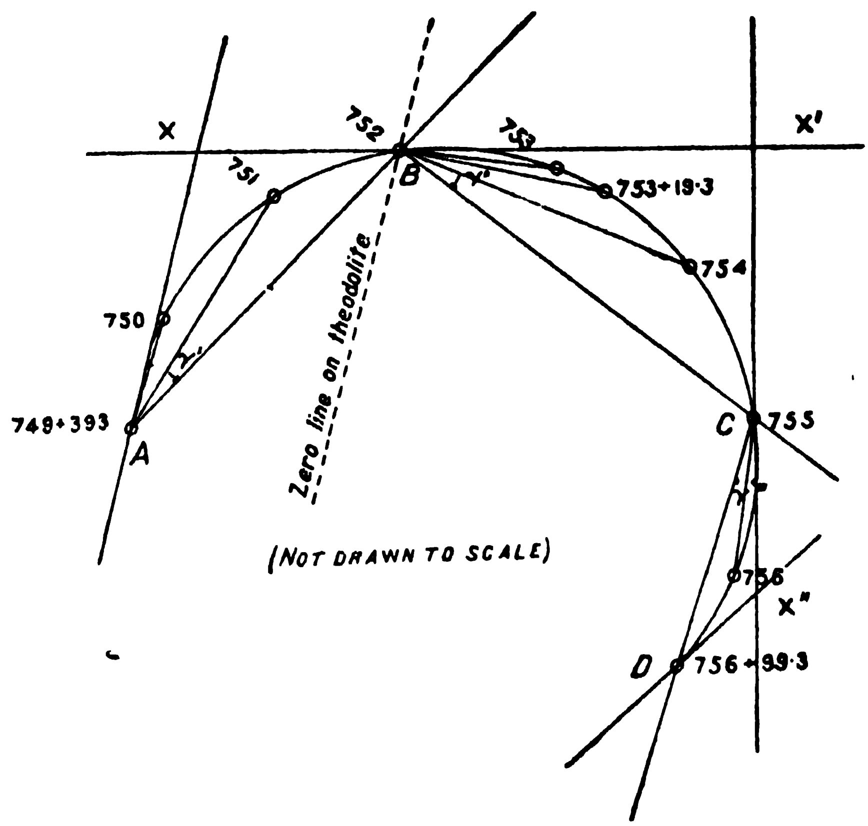
The tabular statement and field book [Plate XV (*a*)] will show how the record should be kept.

Supposing for some reason not more than 300′ can be seen from the theodolite and the instrument has to be moved, then the pegs over which the theodolite would be set, see fig. 83, are stations 749 +39·3, 752, 755 and 756+ 99·3 the last peg, to check the curve and lay out the tangent or straight.

The pegs and distances will remain as before but the angles will alter for this reason that at pegs 752 and 755 the direction of a new tangent will have to be found.

The procedure is as follows :—Peg 752 is fixed as before at reading 6°·31′ the lower plate of the theodolite up to now remaining clamped.

Fig. 83.



On setting up the theodolite at peg 752, the upper plate is found set at reading 6°·31′ the lower plate is then unclamped and the telescope pointed to peg 749+39·3 when the lower plate is clamped on the intersection and thus the instrument will be reading 6°·31′. Next unclamp the upper plate and double the reading or make it 13°·02′ and the telescope will be pointing along the tangent to the curve at this point but in a backward direction that is the angle XBA, fig. 83 has been made equal to the angle XAB so that BX is a tangent to the curve at B. Add 180° to the reading 13°·02′ and direction BX′ will be found so that the direction of the required tangent will be in the line of the telescope when the reading on the theodolite is 193°·02′ or 13°·02′+180°. The instrument could have been transitted or face changed so as to avoid the 180° but this is inadvisable as any collimation error in the instrument is transferred to the line B X′.

The reading of the 753rd peg will be 195°·32′ or 193°·02′+2°·30′ and so on, and the reading of the 755th peg will be 193°·02′+7°·30′ =200°·32′.

The theodolite has again to be removed to peg 755. Set up the instrument at peg 755 and unclamp the lower plate without interfering with the reading 200°·32′ of the upper plate and set the telescope to read peg 752.

Now the angle CBX′ is 7°·30′ and so that the angle BCX′ be also 7°·30′ the reading of the instrument when the telescope is pointing in a

direction CX′ will be 208°·02′. CX′ is a tangent to the curve at C. Again add 180° to the reading of CX′ and the direction of the required tangent at C is found which will be at reading 28°·02′. The 756th peg is put in with the theodolite reading 28°·02′+2°·30′=30° 32′ and the last peg is put in with the theodolite reading 28°·02′+2°·30′+2°·29′=33°·01′.

To obtain the direction of the straight the instrument is moved finally to the T. P. on peg 756+99·3 clamped at a reading of 33°·01′. Peg 755 is again intersected at 33°·01′ by unclamping the lower plate and reclamping on the intersection peg 755. The value of the angle DCX″ is added by releasing the upper plate and clamping it again at reading 33°·01′+4°·59′ = 38°. Add 180° and the telescope will be pointing down the straight at reading 218°. At every even station, that is 2nd, 4th, 6th, &c., there will be this difference of 180° which after all is not inconvenient and to avoid it, would mean bringing in any collimation error there is in the instrument. The field book and tabular statement are given in Plate XV (*b*).

If the curve is left handed then the readings on the theodolite will be anti clockwise from 360° so the angles will be subtracted from 360°, &c.

188. *Method* 2.—**Setting out a curve with two theodolites.**—This method requires fairly open flat ground and of course two men at the instruments. No measurements are necessary as the intersection of the lines of sight from the TPs fixes the position of the pegs.

One surveyor would be putting in a right handed curve and the other a left handed one, that is to say if both theodolites are clamped at 0° on the tangent points one surveyor would be reading and setting tangential angles direct on his theodolite as calculated and the other would be reading the values of these angles subtracted from 360°.

The procedure is so obvious that it is unnecessary to further consider it in detail. The method is not recommended as it would require a very intelligent man on the flag and two assistants for instruments are not usually available, and except in very open country, it would be impossible.

189. *Method* 3—**By offsets from the chords produced.**—In fig. 82 VO and CO are radii and CV a chord and CP a chord produced=CV; also CN is a tangent to the circle at C if N is the middle point of PV.

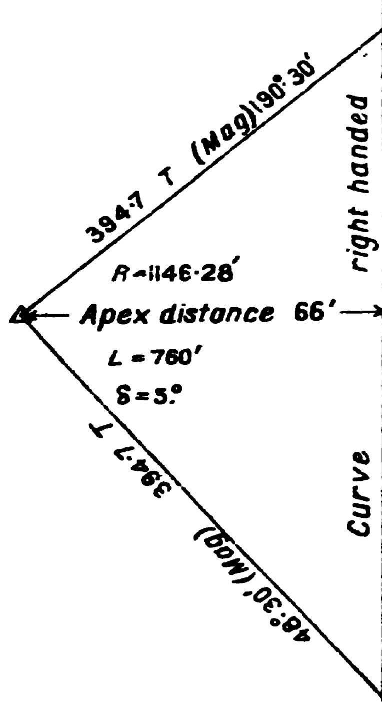
The triangles COV and PC~~N~~V are isosceles and the angle PCV=angle COV therefore they are similar and

CO : CV :: CV : PV (PV is the deflection offset)

∴ PV the offset for a chord produced$=\frac{(\text{chord})^2}{CO}=\frac{(\text{chord})^2}{R}$ and PV is 2NV ∴ NV$=\frac{(\text{chord})^2}{2R}$ (see formula viii, para. 185).

Specimen of field book

Plate XV a.

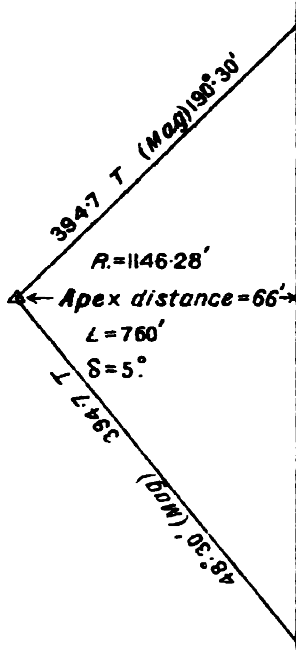


756+99·3	19° 0′ T.P.
756	16° 31′
755	14° 01′
754	11° 31′
753+19·3	9° 30′ Vertex
753	9° 01′
752	6° 31′
751	4° 01′
750	1° 31′
749+39·3	T.P.

	Stations	Distance	Tangential angle as calculated	Tangential angle as used
T.P.	749+39·3			
	750	60·7	1° 31′ 03″	1° 31′ 00″
	751	100	2 · 30 · 00	4 · 01 · 00
	752	100	2 30 · 00	6 · 31 · 00
	753	100	2 30 00	9 · 01 · 00
Vertex	753 + 19·3	19·3	0 28 · 57	9 · 30 · 00
	754	80·7	2 01 · 00	11 · 31 · 00
	755	100	2 30 · 00	14 · 01 · 00
	756	100	2 30 · 00	16 31 · 00
T.P.	756 + 99·3	99·3	2 28 · 57	19 0 · 0

Plate XV b.

Specimen of field book



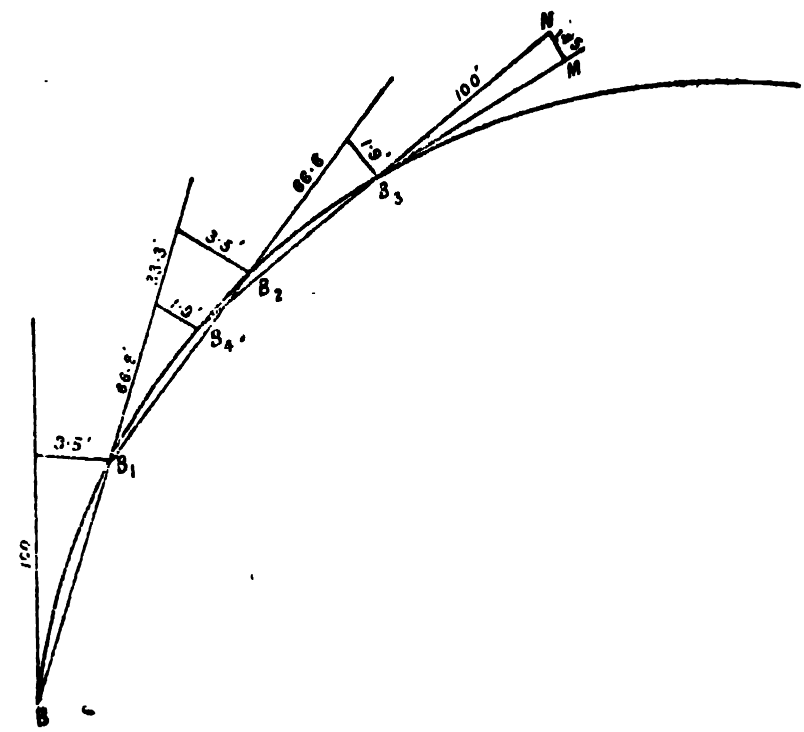
756+99·3	30°01'	T.P.
756	30°32'	
755	200°32'	
754	198°02'	
753+19·3	196°01'	Vertex
753	195°32'	
752	6°31'	
751	4°01'	
750	1°31'	
749+39·3		T.P.

Tabular Statement

Stations	Distance feet	Tangential angle as calculated	Tangential angle as used	Index angle	Remarks.
T.P. 749+39·3		° ' "	° ' "	° ' "	
750	80·7	1.31.03	1.31.00	1.31.00	
751	100	2.30.09	2.30.00	4.01.00	$\gamma' = 6°\ 31'\ 00''$
752	100	2.30.00	2.30.00	6.31.00	
753	100	2.30.00	2.30.00	195.32.00	
V. 753+19·3	19·3	28.57	28.00	196.01.00	$\gamma'' = 7°\ 30'\ 00''$
754	80·7	2.01.03	2.01.00	198.02.00	
755	100'	2.30.00	2.30.00	200.32.00	
756	100'	2.30.00	2.30.00	30.32.00	$\gamma''' = 4°\ 59'\ 00''$
T.P. 756+99·3	99·3	2.28.57	2.29.00	33.01.00	$2(\gamma'+\gamma''+\gamma''') = 38°$
				218. 0.00	is the direction of the straight
			or	38. 0.00	

If the curve is left handed then the readings on the theodolite will be anti clockwise from 360° so the angles will be Subtracted from 360

Fig. 84.



To lay out the curve with chords of 100′ in length the procedure is as follows. Along AX the tangent measure $Ac = 100'$ and at c with an offset $cC = \frac{(\text{chord})^2}{2R}$ find C the first point on the curve. Join AC and produce it to P making $CP = 100'$ and from P lay off an offset $PV = \frac{(\text{chord})^2}{R}$ or as CP is not exactly 100′ two tapes may be used of 100′ stretched from C to P and C to V and a third tape to measure PV to find the point V, that is that PCV is an isosceles triangle. The remaining points are put in a similar manner until the other tangent point is reached and if this is at a full chord's length the new tangent line is resumed by taking half the calculated offset. CN is the direction of the straight at C.

(*a*) **With a sub-chord.**—If the TP occurs at a fraction of the last chord the offset will have to be calculated (a combination of direct proportion and the proportion of squares being used).

Example.—$\gamma = 15°\cdot20'$; $\delta = 2°$; length of chord 100′.

Here by calculation $R = 2864\cdot9$ feet and $L = 766\cdot66'$. The offset from the tangent$=1\cdot75'$, and from the chord $= 3\cdot5'$, see para. 185, formula VIII.

The calculation of the last offset is made by Euclid III·36 and is equal to $\frac{1}{2}\left(\frac{66\cdot6}{100}\times3\cdot5+\frac{(66\cdot6)^2}{(100)^2}\times3\cdot5\right)=1\cdot9'$.* Let B, B_1 and B_2 be the 5th, 6th and 7th peg respectively on the curve in question put in by offsets of 3·5′ from the 100′ chords produced (fig. 84).

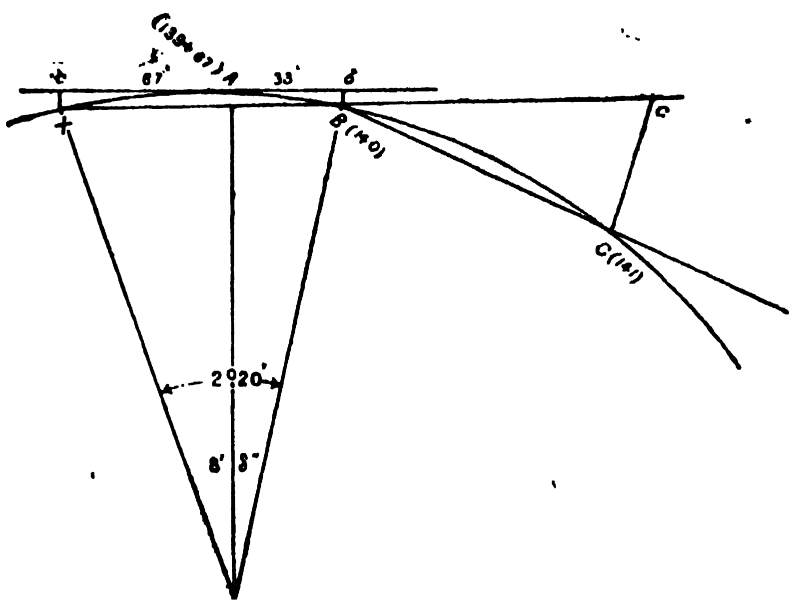
* The offset can also be calculated by the formula :—

$$\text{offset} = 2\,c \times \sin\left\{\frac{\delta}{4}\left(1+\frac{c}{100}\right)\right\}^{\circ} = 2\times66\cdot6\times\sin\cdot833°.$$

To obtain the last point on the curve or TP for the sub-chord $66 \cdot 6'$ produce B_1 B_2 $66 \cdot 6$ feet and lay an offset of $1 \cdot 9'$ at right angles to B_3. This point B_3 will be the TP of the curve. It is required to resume the tangent or direction of the straight and this can be done as follows. Measure $66 \cdot 6'$ on BB_1 produced and with an offset of $1 \cdot 9'$ find B_4 on the curve between B_1 and B_2. Join B_4 to B_3 and produce it $100'$ to N and at N lay off NM equal to the calculated offset for $100'$ of $1 \cdot 75'$. B_3 M will be the resumed tangent.

(*b*) **Starting with a sub-chord**:—Let the PT occur at station $139+67$; $\delta = 2^\circ \cdot 20'$ ($R = 2455 \cdot 7$).

Fig. 85.



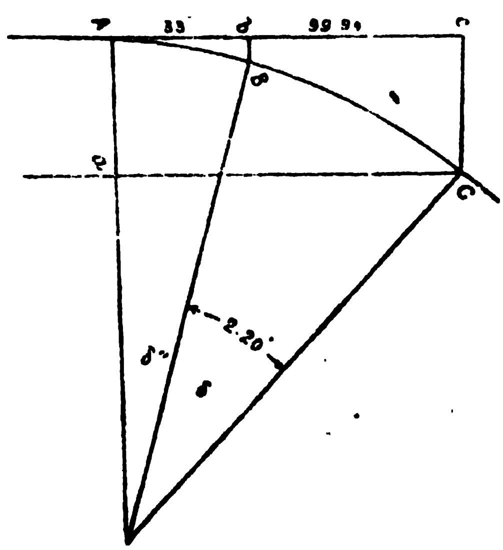
Let A be the PT of the curve and xAb the tangent to the curve at A. (Fig. 85.)

At x, $67'$ back from A set off $xX = 67' \sin \frac{\delta'}{2} = 11$ inches and at b $33'$ forward from A set off $bB = 33' \sin \frac{\delta''}{2} = 2\frac{3}{8}$ inches since $\delta' = 46\frac{4}{5}$ mins and $\frac{\delta''}{2} = 23\frac{1}{3}$ mins.

Now X and B are two points on the curve $100'$ apart and B is station 140. Produce XB to c and make $B\,c = 100'$ also $BC = 100'$ and stretch Cc the deflection offset $= \frac{(\text{chord})^2}{R}$ and find C and continue as already given.

(*c*) **Another method starting with a sub-chord.**

Fig. 86.



Set off as in (*b*) the point B with an offset of $2\frac{3}{8}''$ with a distance along the tangent Abc of $33'$ at b (see fig. 86.)

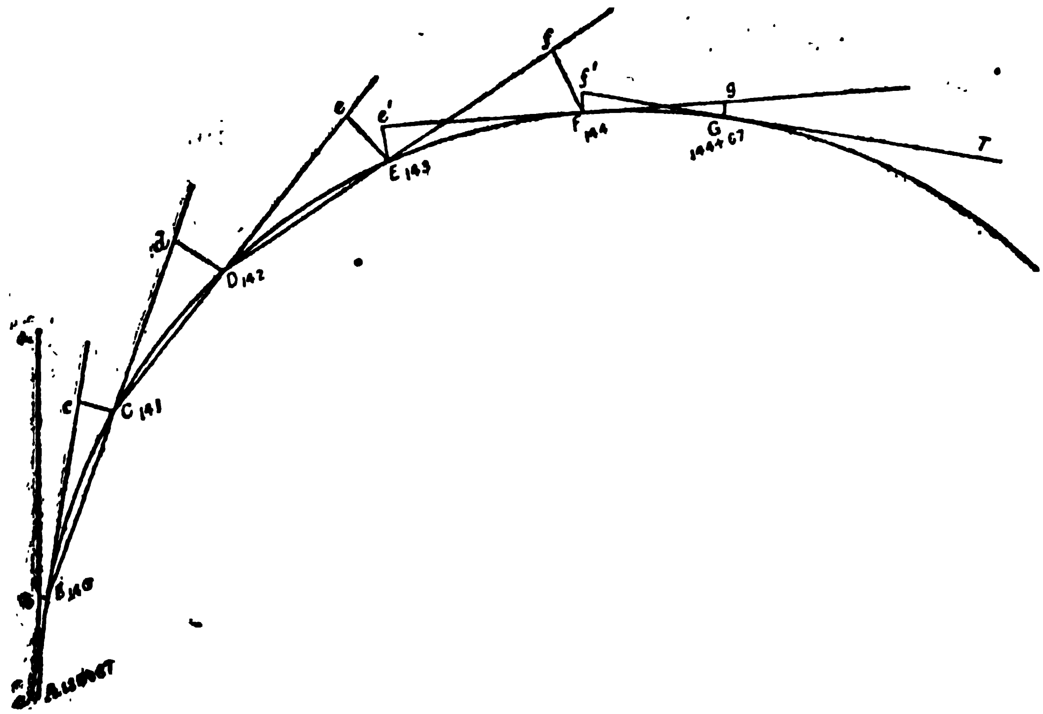
Now $Ac = Ca = R \sin (\delta + \delta'')$.
$= 132 \cdot 94'$.

and $Cc = Aa = R \text{ versin } (\delta + \delta'')$.
$= R \text{ versin } 3^\circ \cdot 07'$.
$= 3 \cdot 63$ feet.

Therefore measure along the tangent a distance Ac equal to $132 \cdot 94'$ and at right angles lay down an offset $Cc = 3 \cdot 63'$ feet when C is found. Join BC and produce it and proceed as before.

(*d*) **Starting and ending with a Sub-chord.**

Fig. 87.



Let the PT occur at station 139+67 ; $\delta = 2^\circ \cdot 20'$
and L=500 feet $\therefore$ closing P T will be at station 144 + 67.

We require to know and find the following :—

R=2455·7 ; tangent offset $= 100 \times \sin \frac{\delta}{2} = \frac{(\text{chord})^2}{2R} = 2{\cdot}036' = Cc$ or Ee ; deflection offset$=100 \times \sin \delta = \frac{(\text{chord})^2}{R} = 4{\cdot}07' = Dd = Ee = Ff$.

The shorter offsets for 33 feet and 67 feet will be in proportion to the squares of the distances along the tangents* or

$Aa = Bb = Cc \times \frac{(33)^2}{(100)^2} = \frac{2\cdot036' \times 1089}{10000} = 2{\cdot}64$ inches$\left(= \frac{(\text{chord})^2}{2R} = \frac{(33)^2}{2R}\right.$ approximate) ; also $Ff' = Gg = Cc \times \frac{(67)^2}{(100)^2} = \frac{2\cdot036 \times 4489}{10000} = 10\cdot97$ inches$\left(= \frac{(\text{chord})^2}{2R} = \frac{(67)^2}{2R}\right.$ approximate) ; Aa is also $= 33 \times \sin \frac{\delta'}{2}$ and $Ff' = 67 \times \sin \frac{\delta''}{2}$.

(*e*) **to lay out the curve** the following order may be observed :—

(1) Measure along the tangent a distance $Ab = 33$ feet (it is very nearly 33′) and set off b B at right angles=2·64 inches.

(2) Set off Aa at right angles=2·64 inches.

(3) Join aB and produce it to c making Bc=100 (actually 99·993) and at c set off cC at right angles=2·036′

(4) Join B C and produce it to d making Cd=100′ and stretch also C D = 100′ and with D d = 4·07′ (Cd is nearly 100′) fix position of D.

---

* $Aa = \frac{(33)^2}{R}$ and $Cc = \frac{(100)^2}{2R} \therefore Aa = \frac{Cc \times (33)^2}{(100)^2}$

(5) Find points E and F in a similar manner to (4).

(6) At E set off $Ee' = 2{\cdot}036'$ by preferably the isosceles triangle method though there will be no appreciable error if we consider Ee' at right angles to E F.

(7) Join $e'F$ and produce it 67′ to g.

(8) At g lay down offset $gG = 10{\cdot}97''$ (11″ approximate) and similarly at F lay down offset $Ff' = 10{\cdot}97''$

(9) Join $f'G$ and produce it for the tangent.

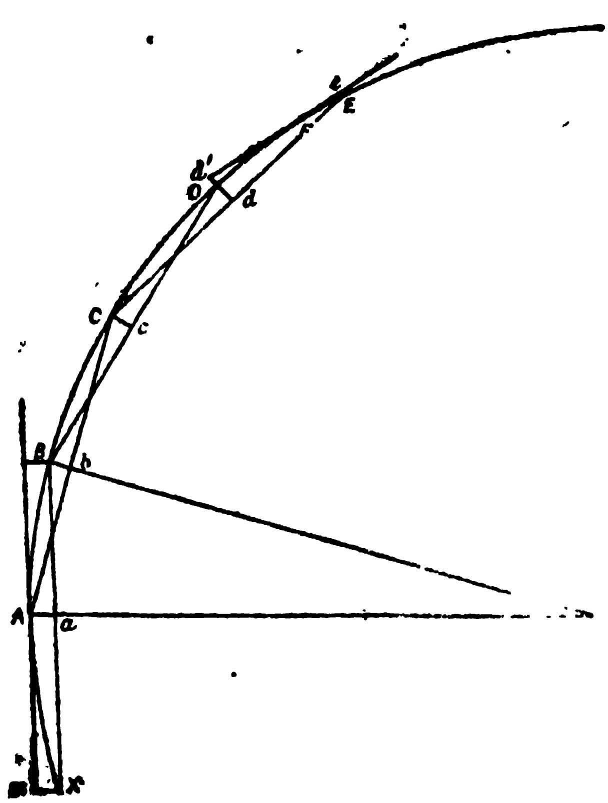
A, B, C, D, E, F and G are thus points on the curve (see fig. 87).

The reader will notice that starting with a sub-chord, if short, any error in laying down the first point will be exaggerated as the curve proceeds and hence it is recommended that in all cases the curve be laid down starting with 100′ lengths till the sub-chord is reached just before the T P.

If, for example, the length of the curve had been 333′ instead of 500 feet the stations would be numbered 139+67, 140+67, 141+67, 142+67 and 143+00. The last length or sub-chord of 33′, the straight, &c., would have been measured and found with an offset of 2·64 inches. If necessary, when the curve is laid down, the chaining and fixing of whole number stations, such as 140, 141, &c., can subsequently be measured along the curve and the procedure very much simplified and the curve more accurate.

190. *Method* 4.—**By offsets inside the curve.**—This method is useful where it is impossible to take offsets from the tangents which happens usually in streets.

Fig. 88.



For example it is required to put in a 10° curve of 183′ length from a given point A. Let Ax be the tangent direction.

The midordinate Aa will equal R versin of half the angle subtending a full chord of 100′ and if a or $aX = 50'$ then $Aa = R$ (versin 5° = 2·18′ (or $\frac{(50)^2}{2R}$ approximate).

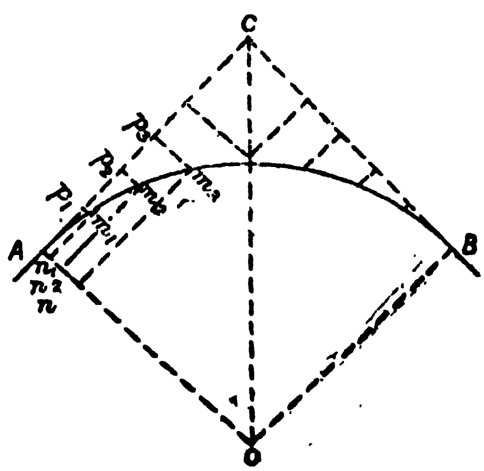
We proceed to lay down the curve up to the subchord. Along the tangent, Ax is measured back as 50′, and offsets Aa and xX are taken with a distance of 2·18′. Xa is joined and produced to B, that is when the chain or tape of 100′ is stretched from X to B the distance Aa at 50′ must be 2·18′. B is a point on the curve 50′ from A. Again the chain or tape is stretched from A to C so that the distance from B= 2·18′. C is found 100′ from A and so on to E 100′ from C.

The P T in this case is 33′ from D towards E and d'D= 33× Sin 1° ·40′=·96′ so in d D produced lay off Dd' = ·96′ and from E lay off Ee = 17 sin 50′=·25′. Join $d'e$ and from d' measure 33′ to F. F will now be the P T of the curve and Fe the straight.

If further intermediate points along the curve are required it is necessary only to compute the midordinates and set them off. For instance the distance AB in the above example is 50′ and the angle subtended at the centre is 5° the midordinate is therefore 1·09′ or R versin 2½° and if the tape of 50′ is stretched between A and B, B and C, &c., and offsets at 25′ or midway of 1·09′ are made to points, these points will be points on the curve.

191. *Method* 5.—**By offsets from the tangent.**—Sometimes the ground without the curve only is adapted for chain measurements. In which case, when the curve is not a long one, i.e., does not exceed say one quarter of its radius, the following method may be found useful. Lay off equal distances Ap_1, $p_1 p_2$, $p_2 p_3$ &c., from A along AO, and perpendicular off-sets $p_1 m_1$ $p_2 m_2$, &c., the points m_1 m_2, &c., fix the curve.

Fig 89.



To find these off-sets—

$$p_1 m_1 = Ap_1 \tan CAm_1$$
$$p_2 m_2 = 2^2 \times p_1 m_1$$
$$p_n m_n = n^2 \times p_1 m_1$$

For draw $m_1 n_1$, $m_2 n_2$, &c., perpendicular to AO.

Then $m_1 n_1^2 = Ap_1^2 = An_1 (2r - An_1)$

$= An_1 \times 2r$, nearly, since An_1 is very small compared with r

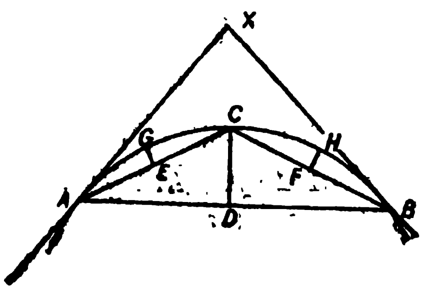
$= p_1 m_1 \times 2r$

$$m_2 n_2^2 = Ap_2^2 = 2^2 Ap_1^2 = An_2 \times 2r, \text{ nearly}$$
$$= p_2 m_2 \times 2r$$
$$\therefore p_2 m_2 : p_1 m_1 : : 2^2 Ap_1^2 : Ap_1^2$$
$$\text{or } p_2 m_2 = 2^2 p_1 m_1$$
$$\text{similarly, } p_3 m_3 = 3 p \ m_1$$
$$\&c., = \&c.$$

These off-sets are very easily and expeditiously laid off by means of a pocket sextant set to read 90°.

192. *Method* 6.—**The versin method.**—Let the points A and B

Fig. 90.

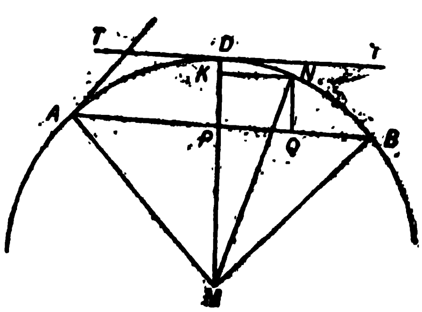


(fig. 90) represent the TPs of the curve and since the direction of the tangents is known the angle XAB or γ is known. Measure the long chord C=AB and since AB=2R sin γ $\therefore$ R is known and hence DC or V =R versin γ is known.

To lay down the curve measure the distance AB bisect it in D and erect the midordinate DC = R versin γ. C will represent the vertex of the curve. Again join AC and BC and bisect them and erect ordinates EG and FH = R versin $\frac{\gamma}{2}$ and so on till sufficient points are found to set down .he curve.

193. *Method* 7.—**To set out a curve from ordinates taken at right angles to a long chord.**—This method is very accurate for short curves

Fig. 91.



and is extremely useful when curves have to be laid out in forest lands as it saves a deal of needless cutting and clearing.

In fig. 91 let AB equal the long chord C and AM = R. PD is the middle ordinate = V. Then since C = 2R sin γ and $R^2 = AP^2 + PM^2$ and since also AP = $\frac{C}{2}$ and PM = R − V.

$$\therefore R^2 = \left(\frac{C}{2}\right)^2 + (R - V)^2.$$

$$\text{or } R - V = \sqrt{R^2 - \left(\frac{C}{2}\right)^2}$$

$$\therefore V = R - \sqrt{R^2 - \left(\frac{C}{2}\right)^2}. \qquad \text{see formula ix.}$$

Take any abscissa $PQ = x$ and let QN be the ordinate o. Join MN and through N draw NK parallel to PQ.

$$\text{Then } MN^2 = R^2 = KN^2 + KM^2 = x^2 + KM^2.$$

$$\therefore R^2 - x^2 = KM^2.$$

$$\therefore \sqrt{R^2 - x^2} = KM.$$

$$\text{Now o the ordinate} = KM - PM \text{ and } PM = R - V.$$

$$\therefore o = \sqrt{R^2 - x^2} - (R - V) \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{x.}$$

Again $DP\,(2R-DP) = AP \times PB$ (Euclid III ·35) $\therefore V\,(2R-V) = \frac{C}{2} \times \frac{C}{2} = \frac{C^2}{4}$ now V^2 is small in comparison with R and in all practical cases may be neglected.

$$\therefore 2RV = \frac{C^2}{4} \quad \therefore V = \frac{C^2}{8R} \text{(very nearly).}$$

If there happened to be an obstruction such as a building which prevented certain ordinates being measured from AB then a tangent TT could be aligned parallel to AB and the ordinates from TT would be $V - o$. V and o being calculated as before.

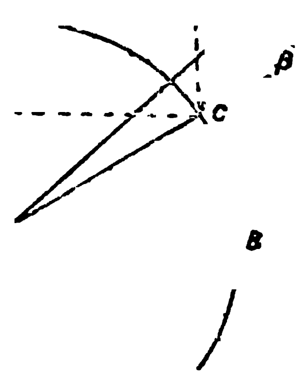
Example.—Having selected two tangent points on a curve for a tramway it was found that the distance between was 131′ and that the total deflection angle was 34°. Find the values of abscissæ and ordinates.

Here $C = 2R \sin \gamma = 2R \sin 17° \therefore R = 224'$ and $V = 9{\cdot}8$.

By taking $C = 131'$ and dividing it into 10 parts each equal to 13·1′ then the fifth ordinate will be midway or at 65·5′ from the TPs. By putting $x = 13{\cdot}1,\ 26{\cdot}2,\ 39{\cdot}3$ and $52{\cdot}4$ we obtain the following values for the ordinates measured from the middle ordinate outwards, viz. 9·4, 8·2, 6·3, and 3·6.

194. *Problem.*—It sometimes happens that having been given the tangents it is required to know what curvature might be given so that the curve will pass through some certain point on the ground that is AX and BX are given and the angle β. Find a curve which shall pass through the point C and join the two tangents.

Fig. 92.



Let $\beta = 14°$ and with the theodolite at X let the angle AXC measure 130° and XC measure 44′. It is required to find a suitable curve which will join A X and B X and pass through the point C.

Join OX and OC and through C draw CE at right angles to AX.

The angle $AXB = 166^\circ$ and hence angle $BXO = \frac{166^\circ}{2} = 83^\circ =$ angle AXO; and angle $OXC = 130^\circ - 83^\circ = 47^\circ$.

$$\text{Now } \frac{OA}{XO} = \sin 83^\circ \therefore XO = \frac{R}{\sin 83^\circ}.$$

In the triangle XOC $XO : OC :: \sin XCO : \sin 47^\circ$.

$$\therefore \sin XCO = \frac{XO \sin 47^\circ}{R} = \frac{R}{\sin 83^\circ} \times \frac{\sin 47^\circ}{R}$$

$$= \frac{\sin 47^\circ}{\sin 83^\circ} \therefore XCO = 132^\circ \cdot 32'$$

and since the angle $OXC = 47^\circ$ and $XCO = 132^\circ \cdot 32'$.

$\therefore$ the angle $XOC = 28$ mins.

Again the angle $A\,O\,C =$ angle $A\,O\,X +$ angle $X\,O\,C = 7^\circ \cdot 28'$

and R vers $A\,O\,C = E\,C$ and $E\,C = C\,X \sin AXC$.

$\therefore R$ vers $A\,O\,C = C\,X \sin A\,X\,C$.

$= 44$ feet $\times \sin 130^\circ$.

$$\therefore R = \frac{44 \times \sin 130^\circ}{\text{versin } 7^\circ \cdot 28'} = 3975'$$

and $R = \frac{50}{\sin\frac{\delta}{2}} \therefore \sin\frac{\delta}{2} = 0 \cdot 01251$ or $\delta = 1^\circ \cdot 26' \cdot 24.''$

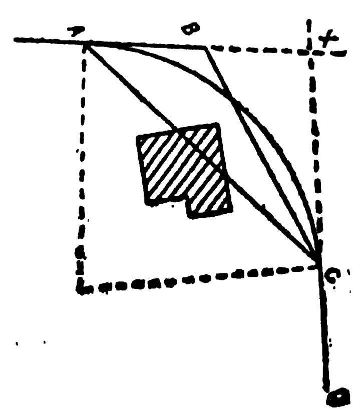
Now half central angle $= \gamma = 7^\circ$ and $T = R \tan \gamma$.

therefore A X and B X are 488′ from X.

195. *Problem*.—**When the intersection point is not visible.**

Let A B and D C be the direction of the two tangents and let B and C be intervisible. It is required to join A B to C D by a suitable curve (fig. 93.)

Fig. 93.



Procedure.—Measure the line B C also the angles A B C and B C D.

The intersection angle between the tangents will be equal to angle $A\,B\,C +$ angle $B\,C\,D - 180^\circ$ and $\gamma = \frac{360^\circ - \text{angle } A\,B\,C - \text{angle } BCD}{2}$.

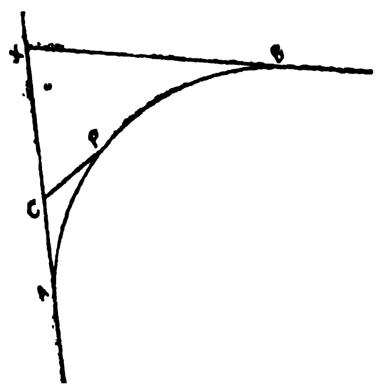
$$\text{Now } X\,B = \frac{B\,C \sin X\,C\,B}{\sin B\,X\,C} \text{ and } X\,C = \frac{B\,C \sin X\,B\,C}{\sin B\,X\,C}$$

$\therefore$ X B and X C are found and since $X\,C = X\,B + A\,B$. $\therefore$ A B is known and can be measured back along the tangent from B and thus A and C need not also be intervisible.

also $X\,C = R \tan \gamma$ $\therefore$ R is known &c.

196. *Problem* **to find a certain point on the curve.**—It sometimes happens that a certain point or points on the curve such as a 1000 foot peg is required to be fixed on a curve or there is (see fig 94.) say an obstacle between A and P and the work up to P requires checking before proceeding on to B; the point P can be fixed as follows:—

Fig. 94.



Let $\delta = 2°$ and $\beta = 40°$ and chainage at T C = 101·59. It is required to fix for check purposes the peg at chainage 110·00 at P.

Now L = A P = 110·00′ − 101·59′ = 841′

The central angle subtended by A P will be $8 \cdot 41 \times 2° = 16° \cdot 49' \cdot 12''$ and if C P is a tangent at P then C P = C A = $\frac{5729 \cdot 58}{2} \times \tan 8° 24' \cdot 36'' = 423 \cdot 55'$

Therefore P can be fixed by measuring 423·55′ to C along A X and at C an angle of 16° ·49′ ·12″ is set off which is the angle X C P and C P is measured 423·55′ to P.

Now C P is a tangent to the curve at P and if the theodolite is being used the direction P C at P can be utilised for laying out the next portion of the curve since it is supposed that an obstacle such as a high bank or jungle exists which intercepts the direction P A.

Compound curves.

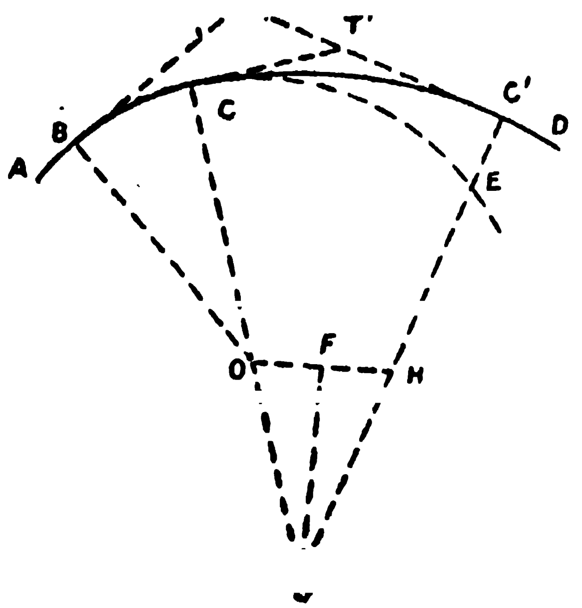
197. **Compound curves.**—The following are only the geometric solutions to make calculations by. The curves are actually laid as previously described. A compound curve may consist of two, three or more portions of arcs of different radii and is adopted where the line is required to pass through given points to avoid obstructions, or where a principal station or terminus is required.

Case I. **To find the radius of the second curve, the two tangents, the starting point and one radius being given.**

In fig. 95 from the given point B in the tangent AT, draw the given radius BO perpendicular to AB; and draw the curve to some point C, where it is found convenient to change the radius; draw the radius OC, and

perpendicular thereto draw CT′, meeting the tangent DT in T′; make T′ C′=T′C, and from C′ draw C′ O′ at right angles to TC′ meeting CO, prolonged if necessary, in O′; then O′ is the centre of the arc CC′ of the curve, conformably to the nature of tangents.

Fig. 95.



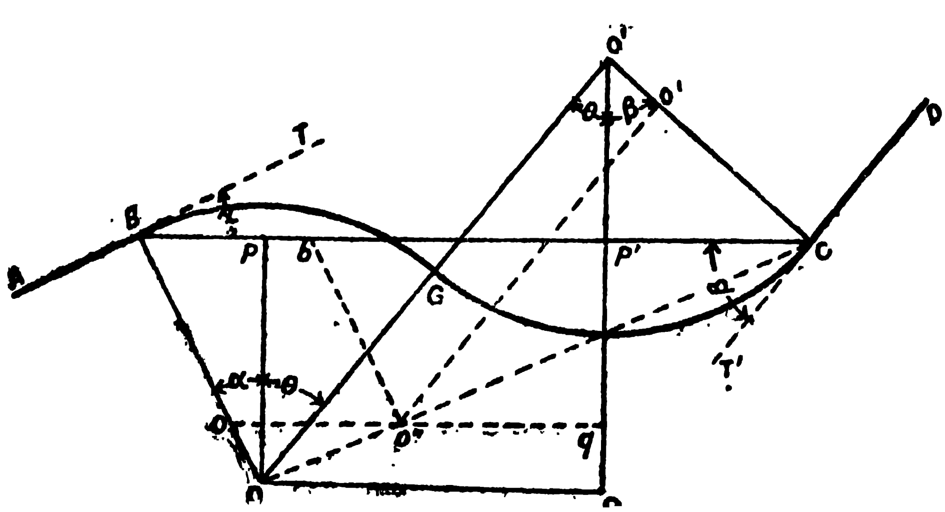
Case II. **One of the two radii of the compound curve, and its starting and closing points being given, to find the other radius.**

Let AB, C′D(fig. 95)be the tangents, B and C′ the starting and closing points of the curve. Draw the lines BO, C′H each= given radius and perpendicular to the tangents; join OH, and bisect it in F; draw O′F perpendicular to OH, meeting C′H prolonged in O′; join OO′ and prolong it till OC=C′H; then the points O, O′, are the centres of the arcs BC, CC′, which constitute the curve, O′C=O′C′ being the radius required.

Case III. **When the two portions have the same radius, to determine that radius, the tangential points and their distance apart being given.**

In fig. 96 let AB, CD be the tangents, B and C the given tangential points, and BC the given distance, draw B*o*=C*o*′ respectively, perpendicular to AB, CD and of any convenient length; through *O*, parallel to BC, draw *oq* indefinitely; with the compasses apply *o*′ *o*″=2C*o*′=2B*o*

Fig. 96.



cutting oq in o''; through C, draw $Co''O$, meeting Bo prolonged in O, and through O, parallel to o'' o', draw OO′ meeting Co' prolonged in O′; then O, O′ are the centres, and OB and O′C are the equal radii of the serpentine curve BGC; the common normal of the portions BG and GC of the curve being $OGO'=2BO=2CO'$.

Draw OP and O′P′ perpendicular to BC and OQ parallel to BC.

Trigonometrical Solution of Case III.—If

$$\left.\begin{aligned} OB&=O'C=r \\ TBC&=\alpha,\ BCT'=\beta \\ POO'&=OO'Q=\theta \end{aligned}\right\}$$

Then $BP+PP'+P'C=BC$, or, $r \sin \alpha + 2r \sin \theta + r \sin \beta = BC$, (1)

Again, $OO'=2r$, or, $\frac{OP}{\cos \theta}+\frac{O'P'}{\cos \theta}=\frac{r(\cos \alpha + \cos \beta)}{\cos \theta}=2r.$

$$\therefore \cos \alpha + \cos \beta = 2 \cos \theta, \;\ldots\ldots\ldots\ldots (2).$$

Hence, r and θ are known.

Example.—Given two tangents A B and C D not parallel and B and C the starting and ending points on the S curve and B C the distance between. Find the common radii if $\alpha = 15°$ $\beta = 20°$ and B C = 1500′.

By formula.—$\cos \alpha + \cos \beta = 2 \cos \theta$.

$$\therefore \frac{\cos 15° + \cos 20°}{2} = \cos \theta.$$

$\cdot 9528092 = \cos \theta \;\therefore\; \theta = 72° \cdot 20'$ very nearly.

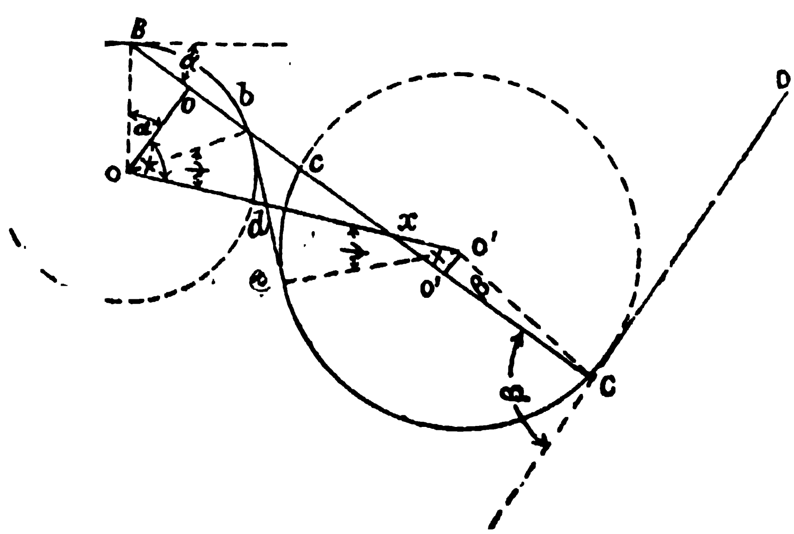
also $BC = r \sin \alpha + 2r \sin \theta + r \sin \beta$.

$$\therefore r = \frac{BC}{\sin \alpha + 2 \sin \theta + \sin \beta} = \frac{BC}{\sin 15° + 2 \sin 72° \cdot 20 + \sin 20°}$$

$$= \frac{1500}{1 \cdot 2077967} = 1242' \text{ nearly.}$$

198. **Two segments joined by straight portion.**

Fig. 97.



Given—
$BO = r$
$CO' = R$
$BC = l$
$ABC = \pi - \alpha$
$BCD = \pi - \beta$

Required the lengths of the arcs Bb and C e and also that of be which is a common tangent to the two circles, we have—

$$l = Bo + oo' + Co' = r \sin\alpha + (r \cos\alpha + R\cos\beta)\tan\chi + R\sin\beta$$

$$\therefore \tan\chi = \frac{l - (r\sin\alpha + R\sin\beta)}{r\cos\alpha + R\cos\beta)}$$

Hence χ is known.

$$\text{Now } OO' = \frac{Oo + O'o'}{\cos\chi} = \frac{r\cos\alpha + R\cos\beta}{\cos\chi}$$

$$\text{and also } OO' = \frac{Ob + O'e}{\cos\psi} = \frac{r + R}{\cos\psi}$$

$$\cos\psi = \frac{(R + r)\cos\chi}{r\cos\alpha + R\cos\beta}$$

$$\left.\begin{aligned} \text{Hence } BOb &= (\alpha + \chi) - \psi \\ CO'e &= (\beta + \chi) - \psi \\ be &= (R + r)\tan\psi \end{aligned}\right\}$$ and required lengths of arcs B b, Ce, and length be are known.

Example.—It is required to join two lines of railway with a 1° and 2° curve having a piece of straight. The starting and closing TPs are 8000′ apart and the straight line joining the TPs is observed to make angles of 160° and 140° respectively with the tangents. Given the chainage of the TP of the first curve as 576+10, find the chainage of the commencement and end of the piece of straight and the closing TP.

The following data in fig. 96 are known :—

$$BO = 5730 \ (r \text{ for } 1° \text{ curve})$$
$$CO' = 2864{\cdot}9 \ (R \text{ for } 2° \text{ curve})$$
$$BC = 8000 \text{ feet}$$
$$\alpha = \pi - 160° = 20°$$
$$\beta = \pi - 140° = 40°$$

$$\text{Now } \tan\chi = \frac{8000 - (r\sin\alpha + R\sin\beta)}{r\cos\alpha + R\cos\beta} = {\cdot}553895$$

$$\therefore \chi = 28° \ 59' \text{ nearly}$$

$$\text{Cos } \psi = \frac{(R + r)\cos\chi}{r\cos\alpha + R\cos\beta} = {\cdot}99198$$

$$\therefore \psi = 7° \ 15\tfrac{1}{2}'$$

$$\therefore \text{angle } BOb = 41° \ {\cdot}43\tfrac{1}{2}'$$

$$\text{and angle } CO'e = 61° \ 43\tfrac{1}{2}'$$

and $be = (r + R)\tan\psi = 8595 \tan\psi = 1094{\cdot}7$ feet and therefore the chainage of b the end of the first curve $= (576 + 10) + (41 + 72{\cdot}5) = 617 + 82{\cdot}5$; and chainage of e the TP of the second curve $= (617 + 82{\cdot}5) + (10 + 94{\cdot}7) = 628 + 77{\cdot}2$ and the TP and end of the second

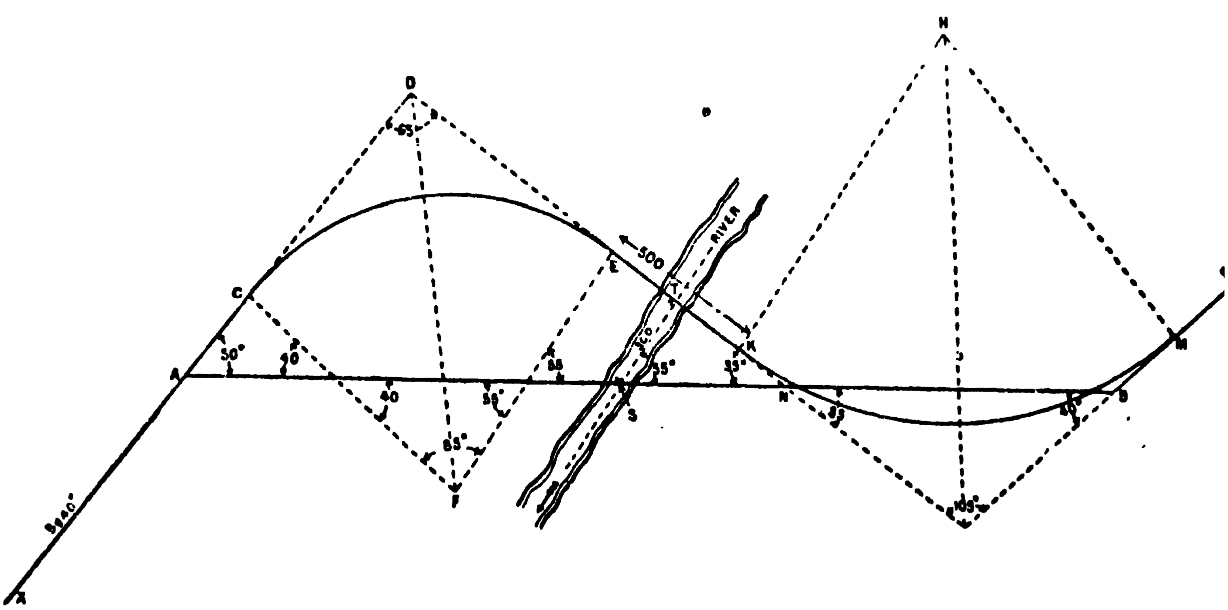
curve$=(628 + 77\cdot2) + (30 + 86\cdot3) = 659 + 63\cdot5$. The curve would be pegged out by Method 1.

NOTE.—If AB and CD were parallel then angle α would equal the angle β.

Problem.—In running a traverse for a line of railway an engineer goes along a line XA bearing 40°. The chainage up to A is 12000. He then turns to the right and continues to a point B 3000 feet from A, the bearing of AB being 90°. From B he changes his direction and continues on at a bearing of 50° to Y. At chainage 13400 he crosses the centre line of a stream 100 feet wide at an angle of 55°. In examining the ground for a site for a bridge he selects a spot 300′ upstream to the centre of the bridge measured along the centre of the stream. The bridge is to be at right angles to the stream.

He now wishes to put in a reverse curve joining up the lines XA and BY and has to leave a piece of straight 250′ on each side of the centre of the bridge. What would be the radii of each of the curves he would use? Also where would the reverse curve start and end?

Fig. 98.



In the triangle S T N (fig. 97) we have:—

$$\frac{\text{T N}}{300} = \tan 55^\circ$$

$$\therefore \text{T N} = 300 \times \tan 55^\circ$$

$$= 300 \times 1\cdot1428148$$

$$= 428\cdot44$$

$$\text{Now T K} = 250 \text{ (by problem)}$$

$$\therefore \text{K N} = 178\cdot44$$

In the same triangle :—

$$\frac{T\,S}{S\,N} = \cos 55^\circ$$

$$\therefore S\,N = T\,S \times \text{sec. } 55^\circ = 300 \times 1{\cdot}74344$$
$$= 523{\cdot}03$$

$$\therefore A\,N = 1923{\cdot}03$$

In the triangle ADN

$$\frac{D\,N}{\sin 50^\circ} = \frac{A\,N}{\sin 95^\circ} \therefore D\,N = \frac{A\,N \sin 50^\circ}{\sin 95^\circ}$$

$$\therefore \log D\,N = \log A\,N + L \sin 50^\circ - L \sin 95^\circ$$
$$= 3{\cdot}2839869 + \bar{1}{\cdot}8842540 - \bar{1}{\cdot}9983442$$
$$= 3{\cdot}1698967$$

$$\therefore DN = 1478{\cdot}75$$

$$\text{Now } E\,N = 500 + 178{\cdot}44 = 678{\cdot}44$$

$$\therefore D\,E = 1478{\cdot}75 - 678{\cdot}44$$
$$= 800{\cdot}31$$

Again in the triangle DFE

$$\frac{E\,F}{E\,D} = \cot \frac{85^\circ}{2}$$

$$\therefore E\,F = E\,D \cot 42\tfrac{1}{2}^\circ$$

$$\therefore \log E\,F = \log E\,D + L \cot 42\tfrac{1}{2}^\circ - 10$$
$$= \log 800{\cdot}31 + {\cdot}0379475$$
$$= 2{\cdot}9032582 + {\cdot}0379475$$
$$= 2{\cdot}9412057$$
$$\therefore E\,F = 873{\cdot}38$$

$$\text{Now } A\,N = 1923{\cdot}03$$

$$\therefore N\,B = 3000 - 1923{\cdot}03$$
$$= 1076{\cdot}97$$

Now in the triangle N G B we know N B and all the angles so we can solve the triangle and therefore know G B and G N we thus know K G, since K G=K N + NG. Knowing K G we find KH; and in the triangle N B G, G B is found and hence B H is known.

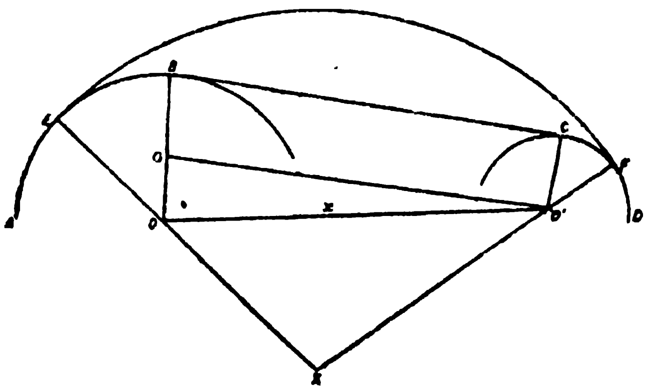
Again in the triangle A D N which we can solve, we find A D.

But we know C D. ∴ we know A C.

Then the points C and M the commencement and end of the reverse curve are known and can be measured on the ground. We see that X A will be produced to C for " take off " of the curve and that the reverse curve will end at point M on B Y.

199. *Problem.*—With reference to the previous example the following is instructive:—

Fig. 99.



To join two curves by a simple curve.

Supposing B C a piece of straight falls across an obstacle it is required to join the two curves by a simple curve and to find the points of tangency. Let A E B be a 3° curve CFD a 4° curve and B C =600 feet it is required to lay down a 1° curve to join these two and to find E and F the points of tangency.

Let O and O′ be the centres of the two curves. Join BO, OO′ and CO′ and through O′ drawn O′G parallel to CB.

Then in the triangle OGO′; OG = R—R′= 477·4 and tan GOO′= $\frac{O'G}{OG} = \frac{600}{477 \cdot 4}$ ∴ GOO′=51°·28′ and OO′ $= \frac{O'G}{\sin O'OG}$ ∴ OO′=767′

Now since EX the radius of 1° curve=5729·7′ ∴ OX =3819·6′ and similarly O′X = 4297·0′

In the triangle OO′X; $\sin \frac{OXO'}{2} = \sqrt{\frac{(S-O)(S-O}{OO'}}$ where S = half the sum of the sides.

∴ OXO′ =8°·30′

and $\frac{\sin OXO'}{x} = \frac{\sin O'OX}{O'X}$ ∴ $\sin O'OX = \frac{\sin OX'O \times O'X}{x}$ ∴ X OO′=124°·06

and 180°−OXO′−O′OX=OO′X ∴ angle OO′X =47°·24′

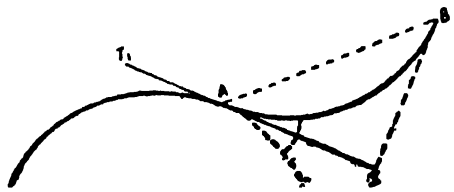
Now angle EOO′= angle OXO′+angle OO′X=55°·54′

and angle EOB= angle EOO′ − angle BOO′=4° 26′ and therefore EB or length of curve to tangent point E is known since it is equal to $\frac{EOB \times 100}{3^{\circ}}$ =117′·7 and similarly C F $= \frac{CO'F \times 100}{4^{\circ}} = \frac{4 \cdot 065 \times 100}{4}$ =101·6′.

The points of tangency are thus found to be 117·7′ back from B as one TP of the new curve and 101·6′forward from C as the other TP of the new curve.

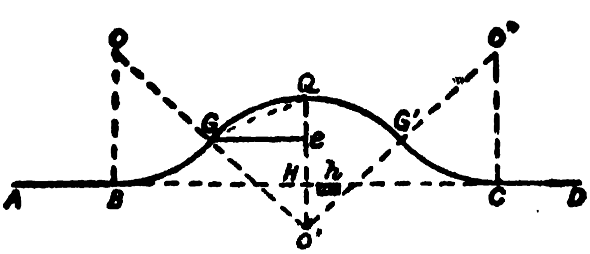
200. In a **serpentine** or **ogee** curve, when an angular instrument is available, the method of setting out the second curve is to set up the theodolite at A, range back on the first tangent point B, set off an angle BAT equal to TBA, add 180°, and lay out the curve from the line AT′ thus obtained. But if no angular instrument is available, the first curve is left, and the second taken up, thus:—When the point A *(the point of contrary flexure)* is reached when setting off the first curve, by setting only half the versed sine the tangent TA is resumed; if then the half versed sine be set off on the other side of the tangent, the first point in the second curve is obtained. The whole versed sine is used for finding the next point, and so on. Reverse curves should however never be permitted in the main line of a railway, as they involve a sudden change of superelevation from one side to the other. Curves in opposite directions should have at least about 200 feet of straight line between them, and they can then be located as two independent curves.

Fig. 100.



201. **Curve of deviation** *or* **diversion.**—In some cases it may be necessary to make a given deviation from a straight line of railway, so that the works may avoid a building or other obstruction situated on or near it, this is done by means of three curves as follows:—Let ABCD (*Fig.* 101) be a straight portion of the railway, h a building or other obstruction on the line. Take HQ of a sufficient length for a deviation, that the line may avoid the object at h; and through Q draw a curve GQG′ of radius QO′ equal to, or greater than, one mile. Draw also two curves BG, G′C of like radius, meeting the first curve at G and G′, and the line at B and C; then the lines OO′ and O′O″ joining the centres of the curves, will pass through their points of contrary flexure at G and G′. Put r = common radius OB = O′Q = O″C, and d = required deviation = HQ; then BH = HC = $\sqrt{d(4r-d)}$, and the four equal chords BG, CG′, &c., are each equal to $\sqrt{dr}$.

Fig. 101.



For from G draw Ge at right angles to QH. Then $Ge = \frac{1}{2}$ BH, and $Qe = \frac{1}{2}\,QH = \frac{d}{2}$.

In the triangle $GO'e$, $Ge^2 = r^2 - (r - \frac{d}{2})^2$. Hence $Ge^2 = \frac{1}{4}d\,(4r - d)$,

$$\therefore\ Ge = \tfrac{1}{2}\sqrt{d\,(4r-d)},\ \therefore\ BH = \sqrt{(d\,4r-d)}.$$

Again $GQ^2 = Ge^2 + Qe^2 = \frac{1}{4}d\ (4r - d) + \frac{d^2}{4} = dr$,

$$\therefore\ GQ = \sqrt{dr}.$$

EXAMPLE—During the construction of permanent bridge the line of rails is to be carried over a temporary bridge which is situated 1,200 feet below the permanent bridge. A diversion curve is to be laid out for the line which is to commence on the river side of a railway station the platform of which ends at 3,500′ from the centre of the permanent bridge. Give the necessary calculations for laying out the curve neglecting the length of the bridge.

In figure BH = 3,500′ and QH = 1,200.

Now B H = $\sqrt{d(4r-d)} = \sqrt{1{,}200\ (4r - 1{,}200)}$ $\therefore$ r = 2,852·08′. If we select a curve having r greater than 2852·08 we will get BH greater than 3,500′ which is impossible under the circumstances.

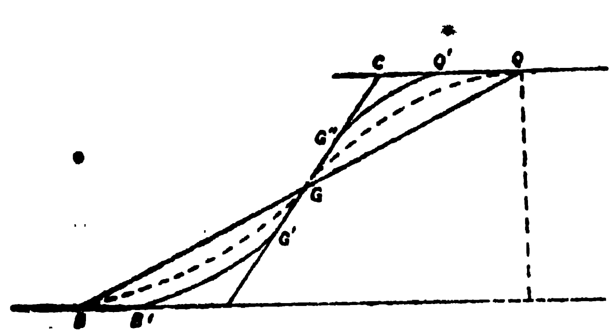
Take the next lower value given in the tables or a radius to a curve of say 2°·6′ curvature or r = 2728·52′ and by substituting the new radius $\frac{BH}{2}$ will be found equal to 1707·1 $\therefore$ BH = 3414, very nearly.

Now if the angle GBH = γ it will represent half the angle of full deviation for each branch of the curve and $\tan\gamma = \frac{1{,}200}{3{,}414}$ = ·351493 $\therefore \gamma$ = 19°·21′·9″ or 19°·22′ very nearly $\therefore 2\gamma = \beta$ = 38°·44′ and length of each branch of the curve = $\frac{38{\cdot}73 \times 100}{2{\cdot}1}$ = 1844·3 and whole chainage = 1844·3 × 4 = 7377·2.

Also BG = $\sqrt{dr}$ = 1809·4 very nearly.

$\therefore$ BQ = 2 × 1809·4 = 3618·8′.

Fig. 102.



202. *Problem.*—The foregoing example does not allow for a piece of straight so let us consider the example again with the data already given and set out a suitable diversion with a piece of straight of suitable length between the two curves.

In figure (102) the dotted line shows the two curves with radius $r = 2852 \cdot 08'$ see previous example with G a point midway between B and Q which is the point of contrary flexure.

From data of previous example $\tan \gamma = \frac{1200}{3500} = \cdot 3428571 \therefore \gamma = 18^\circ \cdot 55\frac{1}{2}'$ nearly = angle CQG or CGQ or GBA or BGA.

Now $BQ = \sqrt{QH^2 + BH^2}$ and $BG = \frac{BQ}{2} = 2 R \sin \gamma$ and since γ is known $\therefore r$ is found for the curves starting at B and ending at Q.

Again the tangents BA, AG, GC, CQ are each equal to $R \tan \gamma = 2852 \cdot 08 \times \cdot 3428571 = 977 \cdot 5'$.

Let the piece of straight required be 70 feet which will be found sufficient for a train travelling on a diversion curve. Then GG′ and GG″ will each equal 35′ or the tangents will be shortened by 35′ and therefore the new tangents will each equal $977 \cdot 5 - 35' = 942 \cdot 5'$ and since γ is constant then by the formula $T = 942 \cdot 5 = R \tan \gamma = R \times \cdot 3428571$.

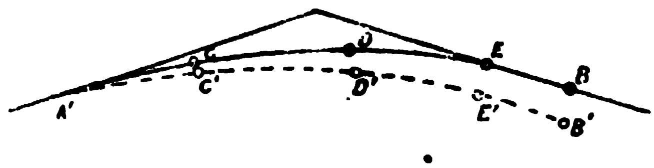
$\therefore R = 2183 \cdot 57' \quad \therefore \delta = 2^\circ \cdot 37'$ very nearly, the curves may be laid down with this angle of curvature or accepting $\delta = 2^\circ \cdot 37'$ the tangents can be recalculated to get an exact value and B′ G′ G″ and Q′ are measured accordingly. It is to be noted that the points A and C can be marked down on the ground by measuring from B and Q respectively a distance of $977 \cdot 5'$. The direction AC is a check on the work at G′ and G″.

203. In laying down a curve in actual practice, it will be sufficient for all practical purposes to fix points at such intervals that the versed sine of the intercepted arc should not exceed $0 \cdot 25'$, or thereabouts. These points may be obtained by off-sets from the tangents when the maximum length of such off-sets does not exceed 30 or 35′, above this limit it will be advisable to adopt the method of off-sets from chords. Calculate the number of chords of a constant length (1,000′ or 2,000′ answer best in practice), the length of the remaining chord contained in the curve, and also the angle contained by two successive chords. Proceed to lay them in the usual way with a theodolite and chain, commencing from one end of the tangents; if correctly done, the end of the last chord will fall on the peg marking the termination of the other tangent.

If there is some difference on closing (and in a long curve this generally occurs in direction, seldom in length), correct thus :—

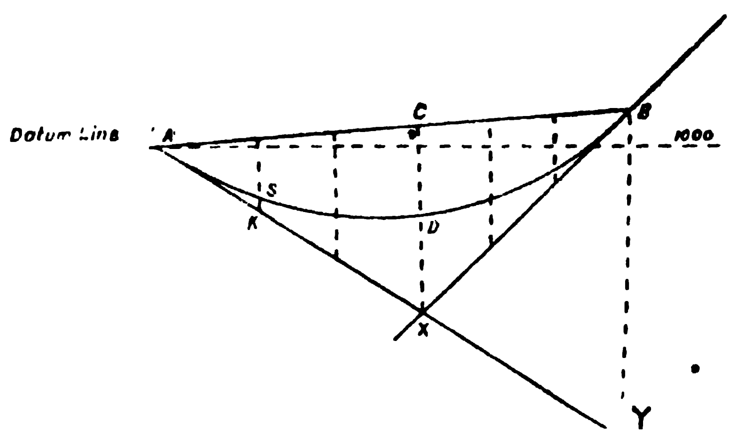
Supposing A′ C′ D′ E′ B′ to be the line as laid down on first trial and ACDEB the correct one; the distance BB′ being measured, the corrections for the other chord ends or distances EE DD′, CC′, may be found by assuming the space between the two curves to be a triangle, and the lines EE′, &c., to be drawn parallel to the base BB′; BB′ and the lengths of the chords being known, the corrections are easily obtained; then returning over the curve correct the positions of the pegs marking chord ends. If the difference in the *length* of the curve is considerable, it will be advisable to go over the work altogether again; this however with careful work, seldom happens.

Fig. 103.



204. **Vertical curves.**—Vertical curves are put in to round off ascending and descending grades on a "summit" or "sag" or they may be put in between an ascending or descending grade with the Level. The parabola is usually used and the vertical curve is a tangent to both grades and the offsets from the tangents vary as the squares of the distances but for most practical purposes if A X and B X(fig. 104) are assumed as tangents to a circular curve the offsets Ks &c., can be calculated by the formula already given, viz. off-set $= \frac{(\text{Chord})^2}{2\text{R}}$.

Fig. 104.



Example.—The levels of A, X and B have been found to be 1000, 995·2 and 1002·4′ respectively and the distance from A to X and X to B to be 300′.

The height of Y must be 990·4 (since gradient is 1·6 %) and thus BY= 1002·4—990·4=12′.

Then by similar triangles BY:CX::AY:AX

$$\therefore CX = \frac{AX \times BY}{AY} = \frac{300 \times 12}{600} = 6$$

$$\therefore DX = 3'$$

(for all practical purposes AB may be assumed to be equal to AY.)

Then since AX is a tangent and DX an offset

$$\text{and since offset} = \frac{\text{Chord}^2}{2R} \;\therefore DX = \frac{AX^2}{2R} = \frac{(300)^2}{2R}$$

$$\therefore R = 15000.$$

and the off-set Ks (if AK=100′) is equal to $\frac{(100^2)}{2 \times 15000} = {\cdot}33$ and any other offset may be calculated from the tangent AY.

The height of K according to the gradient is evidently 1·6′ below A or is at a level 1000—1·6=998·4′.∴ the level of $s = 998{\cdot}4 + {\cdot}33 = 998{\cdot}73'$ and similarly points on the vertical curve with their reduced levels can be found. For 100′ distances the values will be 998·73, 998·2, 998·93, 1000·33 and 1002·4. If the grades are heavy intervals of 50 or even 25′ should be used.

To lay down the curve the following method is advised:—

Close to peg A set up the level or theodolite with, in the case of the former, a footscrew in the direction of the line with the eye end of the telescope just missing a staff held on the peg at A; through the object end of the telescope note the height of the axis of the telescope by the reading on the staff; let it be 4·53. Send the staff to the peg at X and depress the telescope by means of one footscrew on the level or the vertical arc screw on a theodolite till the reading on the staff at X is 4·53.

The line of sight will now be the tangent to the circular curve and all offsets to the curve are subtracted or added as the case may be from or to this line of sight to find points on the curve, e.g. the points in example will for a descending grade, be higher than K and the top of the peg at s will be correct when the staff placed on it reads 4·53— 33 = 4·20 etc.

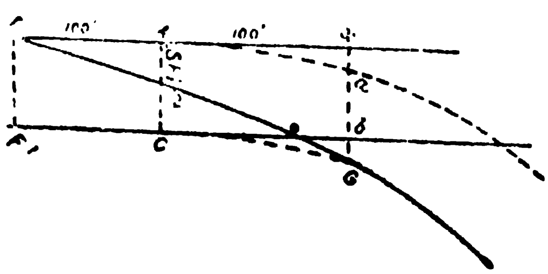
It is more or less essential that X is midway between A and B and if A and B are ruling points on the grade X must be accepted half way with a certain level height but if X is a ruling point then A and B may be adjusted to meet the case.

205. **Transition curves.**—Curves of less than 3° curvature do not require a transition curve. The superelevation on a transition curve is gradual and the full superelevation is reached where the circular curve begins. The superelevation in India is generally about an inch in 36′ on the standard gauge of 5′·6″ and if 5″ is considered as a maximum (the question of the

amount of superelevation is not settled, (see Proceedings Institute Civil Engineers, Volume CLXXVI) the length of the curve of adjustment (l) would in an extreme case be a minimum of 180′ and a maximum of 250′ and Froude lays down that if superelevation is applied at 1 in 300 the length of the curve of adjustment (l)$=300\times$ superelevation or again according to formula:— superelevation in inches $=$ gauge in feet $\times \frac{v^2}{1{\cdot}25R}$ and if the gauge is 5′ ·6″ and $v = 60$ miles an hour and $\delta=3^\circ$ then superelevation $= 8{\cdot}08''$ and with a grade of 1 in 300 since the curve of adjustment (l) $=$ superelevation $\times$ 300 $\therefore$ $l = 201'$. Mr. Morrison in his practical method accepts 200′ as the length of the curve of adjustment. It is necessary now to find the shift as it is called and shift depends on the length of the curve of adjustment and the curvature or shift (s) $= \frac{l^2}{24R}$ in feet or $\frac{l^2}{2R}$ in inches (the latter formula is more easily remembered as it is analogous to the tangential offset formula of $\frac{(\text{chord})^2}{2R}$.

Taking $l = 200'$ and $\delta = 3^\circ$ then shift *in inches $= \frac{(200)^2}{2\times1910} = 10{\cdot}47''$.

Fig. 105.



In figure 105 the original circular curve started from A. It is required to put in a transition curve. From A lay off a point C 10·47″ towards the centre of the curve. A C represents the shift. From A measure AF 100′ back along the tangent and also Ax 100′ forwards along the tangent and from x lay an offset of xa $+$ shift $= \frac{C^2}{2R} +$ shift $= 2{\cdot}62' + {\cdot}87' =$ $3{\cdot}49'$. This is also equal to shift $+$ bG. Thus G the point on the circular curve is found. Join FG and F G will bisect A C and F G will be the transition curve and all offsets from the original tangent to F G will be in proportion to the cubes of the distances along Fx that is F G conforms as near as possible to a cubic parabola.†

* Shift is also given for a 200′ length of adjustment as equal in feet to $\frac{16{\cdot}6}{\text{Radius of curve in chains of 100 feet}} = \frac{16{\cdot}6}{19{\cdot}1}$ feet $= 10{\cdot}44$ inches.

† Example $(Fx)^3 : (FA)^3 :: 3{\cdot}49 : p \therefore p = \frac{100\times100\times100\times3{\cdot}349}{200\times200\times200} = {\cdot}435'$.
Where $p = \frac{1}{2}$ AC $= \frac{1}{2}$ shift $= \frac{{\cdot}87'}{2} = {\cdot}435$

If a theodolite is set up at C and a tangent parallel and at a distance equal to the shift to the original one is aligned then the curve from G is laid out as given in Method 1 (para 187).

In the event of two reverse curves where there is no room to put in a piece of straight both curves would be shifted towards their respective centres and the transition curve would then pass through what would have been the point of contrary flexure.

NOTE.—For more exact methods see paper No. 3065, Volume CXXXIII, Proceedings Civil Engineers by J. Robinson, M.C.I. E. and the Railway Manual.

The tables of offsets (Tables II, III, IV, V and VI) are for curves of radii 5,000′ 10,000′ 15,000′ 20,000′ and 25,000′.

Q. E. D.

CHAPTER IX.

ENGINEERING SURVEYS.

206. The surveying operations described in the foregoing chapters may be considered to have as their general object the completion of a *map* of the country surveyed, more or less accurate according to the time and labour bestowed and the means employed.

Engineering Project.—When however, a survey, is directed to the special object of preparing an *Engineering project*, the preparation of the map must be regarded as subsidiary to the main design,—and the nature of the process employed must be regulated primarily towards the collection of data, which will be necessary in drawing out the project in proper detail.

The ordinary projects which are likely to occupy the attention of engineers in India are those for roads, railways and canals. Projects for drainage and water supply may also be occasionally required and even harbour works and light-houses ; but these last refer to a special branch of surveying, called Marine Surveying, which will not be discussed in this Manual.

In the projects mentioned above, the necessary surveying operation must depend a good deal on what maps already exist of the country affected. Many parts of India have now been so accurately surveyed and mapped, that it may be quite sufficient to trace off the acquired area of country, to an enlarged scale, if necessary. If the enlarged map does not give the necessary details, such details may be readily interpolated by the theodolite, or prismatic compass, or even in the act of running the necessary lines of levels if stadia is used in conjunction with a planetable. But as very few parts of the country have yet been covered, even meagrely, with a net-work of levels, it will in almost every case, be necessary to run such as are required.

If however, no map exists, or none from which leading points may be transferred to an enlarged map with sufficient accuracy, it will be necessary to direct the preliminary surveys to the construction of such a map.

207. **Preliminary surveys.**—The surveyor who is called upon to prepare a map of a given tract of country within a certain time, may often be at a loss to know the best method of starting the survey ; whether to fix a series of points trigonometrically by a net-work of triangles, or else to

work by means of a number of closed traverses, and plot according to Gale's method. If the country is at all hilly, the first method is perhaps the best, and in the end the most expeditious, as then the errors are not cumulative, but are adjusted between station and station. But if the country is level, running traverses without first fixing any points will be found the most expeditious, and in the plains of India sufficiently accurate for all practical purposes. If a trigonometrical survey were resorted to, greater dependence could be placed upon the accuracy of the result, but that amount of accuracy is only obtained by much greater expense of time and labour, owing to the necessity of building high stations from which to observe. In traversing, the errors due to chaining are certainly cumulative throughout the entire circuit, but when the country is moderately level, these errors can with care be reduced to a minimum, and are easily allowed for in the plotting. The details of the survey in either case must be filled in as already explained in Chapter VII.

The least area of country which must be thus surveyed will be determined by considering what is the least area that will be affected by the project under consideration. Thus in the case of an irrigation canal running on the watershed of the country, the boundaries of the survey will clearly be defined by the two main water-courses on the right and left of the watershed line by the highest point on the river from which the canal is to be fed and the lowest point into which it is proposed to tail it. In the case of a railway or road between any two places A and B, the boundaries will be determined by the greatest possible lines of divergence from the straight line AB, *i e.* by the most circuitous route to the right and left of that line which it is possible the road might, with any advantage, be made ; and so on for other cases.

As to the general details which will be required—in the case of a railway or road the following may be enumerated :—The position and comparative size of all towns or villages affected thereby—(if the number of the population can be ascertained it may be written down in the map) —the exact course of any stream which will require bridging between the two extreme points where the bridge would probably have to be made—the cultivated, culturable, or forest land that would be traversed by the line—the position of brick-fields, stone quarries, forests or other materials that might be used in the construction of the line—the position and size of any swamps that might require to be crossed or perhaps drained.

Levels.—The map having thus far been completed, the lines of levels that will be required must next be run, and plotted on the map, the reduced levels being written in at every bench-mark and point of any importance,

or where there are none such, to every 5th station or so, so as not to overcrowd the plan with figures.

Protractor.—A half sheet of "writing imperial" paper, 15″×22″, having a circular protractor of 6 inches radius lithographed in the centre of it, is found to be a very convenient size to protract preliminary lines of levels. The circular protractor is divided by large divisions into degrees, still larger marks show every 5th degree, and by smaller into ¼ degrees, but these marks are not numbered. The surveyor, knowing exactly from his previous field-work how his lines of levels run, draws his own north and south line through that diameter of the protractor which he considers will make his work take somewhat of a diagonal direction across the paper, and then numbers the scale right round for his own convenience. In this way one of these sheets will hold a week's work of some 24 or 25 miles of line levelling, and all the necessary side detail, if drawn to a scale of 1 mile to 1 inch. A specimen sheet with the protractor attached, and the protraction of some levels is here given, (*Plate* XVI) but some of the detail has had to be omitted owing to the reduction of scale.

A plan and section of a circuit of levels is here given (*Plate* XVII) to show the amount of information which should be given, and the student should make a careful inspection of it, for few surveyors' plans and sections contain the whole of the information they should contain.

208. **Road.**—In the case of a road in open level country, it will be enough to level down the line decided on, or along the trial lines previous to the actual one being fixed—the streams to be crossed must also be levelled along and the necessary cross sections taken so as to enable the proper calculations to be made with regard to the waterway, and the reduced levels of flood lines must everywhere be carefully ascertained, to enable the proper height of embankment to be determined. Cross levels will also be required, at points where the line turns and where a curve will be necessary,—also at points where a temporary divergence from the straight may be advisable in order to save work—as for instance, in crossing through a morass or over a hill.

Hill Roads.—To select the trace for a road in a hill region requires much more care and attention. Before anything is definitely decided upon, the several possible lines between the extreme points must be considered, and particular attention should be paid to the mean obligatory points on each line. A cardinal principle to be remembered, also, is that the ascent or descent should be as uniform as possible, the gradients in the opposite direction being reduced to a minimum. Again, an obstacle—such as a steep cliff, chasm, &c., which at first sight may appear impassable except

at inordinate cost, may in reality prove quite otherwise, for in order to avoid it the numerous minor difficulties encountered may in the end prove more expensive. For obvious reasons also deep cuttings into the hill-side should be avoided as much as possible, but when the slope of the hill-side is considerable, the trace of the road should be so selected that the whole of the width of proposed road should be cut out of the solid hill-side.

In commencing a survey for a hill road, the rough obligatory points are usually assumed on the several ridges to be passed, and as the length of the trace in the intermediate valleys is most deceptive and generally much greater than estimated, the relative position of our assumed obligatory point from the next should always be calculated by using a gradient steeper than that required to be worked to. For instance, supposing a road is to be laid out on a gradient of 1 in 20, a position on one ridge is known, and it is required to estimate where the trace may cut the next ridge. The intermediate distance is so difficult to approximate to, and so generally under-estimated, that the point on the next ridge is easier found by applying a steeper gradient—say 1 in 17 or 1 in 18—to the estimated length of intermediate road than by adding approximately to the estimate. Again, it must be remembered that when the trace of the road is settled, the resulting gradient on the completed road will work out steeper than that used in laying out the trace. The original trace must, therefore, be somewhat easier than that finally required: and though it is difficult to say what allowance should be made, as it varies with nature of the ground, it may be assumed in a general way that a

slope of	1 in 32	works down to a slope of	1 in 30
,,	1 ,, 22	,, ,,	1 ,, 20
,,	1 ,, 16	,, ,,	1 ,, 15

Zig-zags in mountain roads should be avoided as much as possible, as they frequently involve incessant repairs ; if used they should not be run through rotten ground, or across drainage, but they are less objectionable if they can be arranged so that the drainage of each length can be thrown off at the turning points clear of the road below. The Ghat tracer, Abney level and De Lisle reflecting level are all used in tracing out hill roads.

209. **Railway.**—A survey for a railway is very similar to that for a road, but it is more elaborate, in that greater attention must be given to the gradients, and the several lengths of straight must be connected together by regular curves.

A revised and complete set of "Rules to be observed for the preparation of Railway Projects" to be submitted for the sanction of the Government

of India was issued in 1893, corrected up to 1910 and contains very detailed instructions.

One or more trial lines are generally run before the actual direction of a line of railway is decided upon, and the amount of accuracy bestowed upon the surveys of such trial lines is only sufficient to obtain a fair approximation to accuracy, and to give a reliable comparison between the rival lines. In the preliminary surveys therefore it is not usual to run in regular curves except in difficult country, nor to take more levels than are sufficient to admit of an approximate estimate of the earth work being made. Therefore to make a survey for a trial line of railway, all that is necessary is to run a traverse with a theodolite from one obligatory point to the next and then run a line of levels over the same line.

Owing to facilities for vision, the engineer in running the trial line is apt to put the turning points on the several ridges crossed, but this should be studiously avoided if possible, as if the line is selected for the permanant line, it will have to be re-run, or else the cuttings through the hills will all be on the curve.

It is usual for the surveyor who runs the traverse to put in pegs or marks every 300 or 500 feet along the line of traverse in open country, and every 100 feet in broken or hilly ground, in order that the leveller who follows may not require to do any chaining. These pegs are usually numbered consecutivly, the surveyor continuing the length of the chainage throughout from the beginning, rather than commencing a fresh chainage at each new departure from the previous straight line. It is obvious in this trial survey that the levels are taken along the tangents rather than along the curves, and also that the line of railway is represented as slightly longer than it would be if really located, but the results are quite accurate enough for the purposes of the trial survey. Also in a trial survey the amount of detail to be shown may be reduced to a minimum. Of course more detail of the line is required in difficult country and through towns and villages, but no great accuracy is aimed at as the results desired are in the first instance only comparative. In a trial survey, therefore, all the detail required is to show where obstacles occur near the traversed line, and also the course of rivers and streams for a few hundred yards on each side of the line.

When, however, the course of the railway is decided upon, the work required from the surveyor who has to locate the line is much more delicate. Sufficient detail of the country on either side of the selected line has to be shown, in order that possible minor deviations may be made if it is found that the estimates work out unsatisfactorily and demand a further

investigation. In locating a line it is therefore usual to lay out the several lengths of straight accurately, and to determine the most convenient curves by which to connect them; the line is then traversed over in the ordinary way, and the curves put in as the work proceeds. The chainage is usually continued throughout from the commencement, and pegs put in the centre line at every 100 feet, for the convenience of the leveller who has to follow the man with the theodolite. The detail of the neighbouring country may be also put in by the man who runs the traverse, but it is better to leave all that to an assistant who follows with a plane-table, on which the course of the line with the positions of the 100 feet pegs is accurately marked.

The smallest party required to locate a line of railway with convenient despatch is one Executive Engineer and two assistants. The responsible officer ranges out the line, conducts the traverse, and puts in the curves; one assistant follows with the level, makes an accurate section of the line, and also takes all necessary cross sections; and the other assistant, with the aid of a plane-table and other instruments*, when required, makes a survey of the required belt of country, surveys a sufficient length of the course of all streams crossed, and does the needful check levels. With a large staff the above work can be sub-divided and greater progress made, and assistance is also at hand to run alternative lines through difficult parts, and to make more detailed investigations at river crossings, &c. If it can be arranged, it is advisable that one party be told off to locate a line of railway up to, say in India, 150 or 200 miles in length; and the work should be so regulated that the several officers engaged, work comparatively close to each other. Check levels should be constantly run, and no great advancement should be made by the traverser ahead of the levelling operations until the levels are accurately checked. If a man has of necessity to check his own levels, he should do it in the opposite direction, and only touch on the original line at bench-marks and other obligatory points, but it should be so arranged that the check levels are run independently of the leveller.

As the location of a line of railway usually follows quickly on the trial surveys, it is only necessary to make such preliminary marks as will enable any of the trial lines to be easily found. This can be done by blazing trees, making marks on buildings, &c., by which the line passes close, and by making a semi-permanent mark where the several tangents

* The cross section work and also the detail is easily put in by an assistant working with the level taking stadia readings and shooting in staff positions from his plane-table placed as close as possible to his level.

meet; and if careful sketches and notes of these marks are also entered in the field-books, no difficulty should be experienced in picking up a line again. With a located line the marks must be much more permanent, and it is usual to show by a permanent mark in the actual line each successive mile-post and the ends of every curve. It is also of great assistance if the apex of the tangents is also permanently marked. The centre line is also shown by a continuous cut along the surface of the ground about 6 or 9 inches in depth, a mark generally sufficiently accurate in the plains of India to lay off the dimensions of the ground required for the railway.

210. **Canal.**—The kind of survey required for a canal will depend very much on the nature of the country and the magnitude of the work required to be constructed. In an undulating or hilly country the approximate direction of the irrigation channel is apparent at once, and the positions of the minor distributing channels in all cases vary with local requirements; but a project for a large irrigation canal in the plains of India requires a very extended survey.

For such a project, besides the details required for an accurate representation of the country to be traversed, it is necessary to cover the map with a network of levels; and this is generally done by running a series of roughly parallel lines of levels at distances of about a mile apart, and as nearly as can be estimated at right angles to the general watershed of the country traversed. If these lines of levels are connected at their extremities by other lines of levels, the work will be continuous, and each part serve as a check to the remainder. The best line for the canal will probably at once be evident from the contours deduced from this network of levels, and a fairly approximate estimate may be made without further field work. But if any sand hills, ridges, or large shallow depressions occur, and which have not been sufficiently marked by the general lines of levels run, it will be necessary to run such further lines of levels as will carefully represent the ground at these parts, if needed.

The line of the canal selected will generally run along the highest ridge or backbone of the country, and its alignment should be made as straight as possible. With any appreciable current the outer side of a curved channel will require to be revetted, and so add considerably to the initial expense, unless the curve can be made extremely easy.

211. **Canal Surveys.**—The following instructions, based generally on those issued by Colonel Crofton, R.E., when Chief Engineer of Irrigation in the Punjab, for the conduct of canal surveys, will give what further

information is required. They are applicable to all kinds of engineering surveys.

Trial levelling and surveying.—In addition to the levels of the country surface, a rough survey or reconnaissance is required, which should give information on the following points, *viz* :—Approximate sites of villages or towns, lines of drainage, roads, railways, old water-courses, canal, channels (main or rajbahas), edges of high "bangar" land, remarkable buildings, wells, nature of soils, crops, trees, &c., position of stone or kankar quarries, &c. The places between which roads run, and their bearings (if regularly lined out), should be noted; if on embankment the level of the top surface should be taken. The bearings of regularly lined-out canal channels or irrigation cuts, and the level of their beds at points of crossing, with cross sections at right angles to the direction of each, showing level of full supply are required.

212. *Water level.*— The level of the lowest point in the beds of nalas where crossed; with sections at right angles to their courses, showing level of highest known flood, and date of its occurrence, if ascertainable; the level of surface of water in rivers (noting date of observation); depth of water on lowest point of bed (if obtainable), and level of ordinary and highest known flood; levels of floors of tanks and lowest points of large jhils (swamps) should be observed and connected with the line of levels. The site of such sections taken off the line should invariably be connected with the traverse.

The waterway of all bridges or culverts met with on or near the line of levels should be measured; and the levels of their floors or plinths of abutments, or the bed under the arches if there be no flooring, with highest flood mark, carefully noted.

Wherever a well is met with or used as a bench-mark, the level, of the surface of the water should be noted; the depth below the bench-mark can be measured with sufficient accuracy by the chain. If water is being drawn from the well, the surface will in general be abnormally low, in which case the height at which it usually stands when not in use should if possible be ascertained. The quality of the water, whether sweet or brackish, should also be noted. These observations of the surface level of the springs should never be omitted, when opportunity offers; it is a point of considerable importance.

The colour and description of the soils, whether sandy, clayey, &c.; the presence of the white or brown efflorescence, known as "reh" or "kuller" should be noted.

213. **Drainage lines.**—A complete delineation of the drainage lines of the country being one of the primary objects of the survey, too great care cannot be taken in ascertaining their positions. They may be divided (excluding the large rivers) into two classes; the first easily recognizable by their size; well defined channels running in valleys at some depth below the general level of the country adjoining. Into these and the rivers, innumerable channels of the second class discharge themselves; the exact positions of which are not always to be detected by the level alone. They usually rise in jhils (swamps) lying close to the watershed, and their courses are marked by a series of jhils connected by intermediate low lands; a black, clayey soil, "reh," rank grass, and crops requiring frequent irrigation, such as sugarcane, cotton, &c., generally mark the places where water has lain or over which it flows in considerable quantity. No land of this description should be passed over without enquiry as to whether it is flooded during rain, and from what direction the water comes, and whither it runs off. "Reh" if contained in the soil, always rises to the surface where water has lain for any time and appears in greatest quantity during the cold season.

Large towns or villages will almost invariably be found situated close to lines of drainage, or to low ground where water collects after rain. In those parts of the country which are subject to extensive inundations, villages, especially small ones, will always be found to be situated on land out of the reach of the ordinary inundations; no reliance, however, can be placed on their position as regards extraordinary floods.

Sand hills, or very sandy soil, generally mark a watershed on the "bangar" or high land.

Where a nala or drainage line is crossed, and the level of the lowest point of the bed is observed, great care should be taken to ascertain whether this point is on the general level of the bed; if otherwise, the difference above or below should be measured and noted.

Where drainages are met with, enquiries should be made as to their courses both above and below the line of levels, names of villages near which they pass, &c.: by thus observing them in each successive line of cross section, a very complete plan of the drainage of the country is obtainable, as well as a connected series of levels along the beds of the outfall.

Similar information to that detailed above should be obtained with all levelling or surveying for rajbahas, drainage projects, or any other work connected with irrigation.

In levelling for the longitudinal section of a river, the line should follow generally the main water channel, the stations being invariably on the bank or dry ground near the edge of the stream. The level of the surface of the water at intervals (noting date) of ordinary floods and highest known floods; the position of top and foot of rapids (if any), and level of surface of water at each point to be noted. The depth of water to be measured in the deepest part of the channel where the surface level has been observed. Cross-section at right angles to the direction of the river should be taken at intervals and connected with the series of levels, showing the bed, surface of water, level of ordinary and highest known flood. The survey should show all minor channels and affluents (if any), and as nearly as possible the extent of land under water in high floods. The nature of the bed, whether boulders, sand, clay, &c., should be carefully noted.

Where an impassable object lies directly in the line of direction of the levels, it may be passed by any of the methods shown in Chapter XI.

214. **Bench-marks** should be established at intervals of about 3 miles in *general*, and one close to the crossing of every large nala or line of drainage, but at a place not likely to be washed away; also at the ends of each cross section or line of levels. Existing buildings to be preferred for the purpose (see para. 138).

All canal, road, railway, Great Trigonometrical Survey, or other bench-marks met with *en route*, should be connected with the line of levels.

215. **Admissible error in levelling.**—The error or difference in any circuit of levels ought not to exceed one foot per hundred miles traversed (see para. 144). *Small* errors arising from incorrect reading of the staff not holding it vertical, high wind and such like, are inseparable from all levelling operations, but these will not be found to *accumulate* if the work be carefully done. A tendency, however, has long been observed, though as yet unaccounted for, to a small cumulative error in the direction of the levels; but this is not found to affect practical operations materially. Where great accuracy is required, such as in the proof levels of a canal channel, it is advisable to level twice over the same stations with the same instrument, the second series of levels being carried in the reverse direction to the first; the mean reduced level of each station will be as nearly accurate as it is possible to obtain it.

A prismatic compass held in the hand will be found very useful in filling in details off the line of the series of levels. If the variation of the needle is not identical with that of the level employed, the bearings should be

reduced to the meridian of the latter before entering in the field-book.* Most of the side measurements, where great accuracy is not required, may be made by pacing. Two and-a-half or three feet paces will be found most convenient as admitting of easy reduction to feet. Stadia measurements are now more generally employed and are of course accurate.

216. **Scale.**—The scale generally for protraction of levels should be 1 mile to 1 inch. For the section, the horizontal scale same as for the protraction; the vertical, about 100 times the horizontal. A larger or smaller scale may be necessary for special purposes; they should, however, be *always* measures or aliquot parts of the one-mile-to-the-inch scale.

On every protraction of levels, besides the heading, the following must never be omitted:—Date of the survey, name of the surveyor, scale and meridian line; the numbers attached to the several stations on the section to be identical with those on the protraction.

All details noted in the field-book should be transferred to the protraction or sections; a sketch and a short description of each bench-mark to be entered on the back or margin of the sheet in which its position is shown. The information is thus more accessible than if old field-books have to be searched for it.

If a map is to be compiled from levels or surveys taken with more than one instrument, it will be found best to protract the work done with each instrument, on separate sheets, to be subsequently transferred on to the map.

217. **Running the traverse.**—After the position of the line, which may generally be assumed as the watershed, has been approximately determined by means of the cross sections, or otherwise an accurate traverse with the theodolite should be taken over it, including a survey of the ground for about half a mile in general, or further, if deemed necessary, on each side, which should give information on the following points, *viz.*:—Features of the country, if irregular; nalas, lines of drainage and swamps wherever met with; sand hills or ridges, towns and villages; wells; buildings, whether of masonry or mud; roads, whether regularly lined out or merely cart tracks—if the former, the bearings should be taken; places between which they run (whether tracks or made roads), and whether they are lines of traffic or merely village communications, should be carefully ascertained (this is useful afterwards in determining the sites of bridges); village boundaries, &c.; such minutiae as the boundaries of fields are unnecessary; those of gardens may be useful; in fact, everything which is likely to be of assistance in determining the precise line, or that which it

* See footnote page 58.

would be advisable to avoid if possible. A survey of this nature, carefully taken, will generally admit of choosing a line which will not injure property or disturb existing rights in the least possible degree.

The accuracy of the traverse is the point to be chiefly looked to; the distance between the stations on it should be as long as possible, less than a mile, as the probabilities of accuracy in observation are greater in the case of long than short sights, and the plotting is easier as well as more likely to be accurate. The sights to the station poles should be taken as in ordinary traverse surveying, but should show the magnetic bearing of the lines, or their supplements; these should be checked by repeating the observation at each station, thus:—Clamp the upper plate on zero of the lower and fix on back pole; then turn upper plate round to sight fore pole, noting the angle in the field-book; this angle should equal the difference of the magnetic bearings first observed. This will check the directions of the traverse lines. To check the distances between stations: Fix on a well-defined point some distance to one side, say a mile, and observe to it from every station from which it is visible. If the distances have been measured and plotted correctly, and the bearings are accurate, the latter will all meet in one point on the map.

The above paragraphs regarding traversing should not be adhered to by the surveyor who can fix a true meridian and whose work may be required many years hence. No reliance can be placed on magnetic variations which differ year by year and which are different also in every instrument. The best way to locate a line for present or future use is by a true meridian with inward angles and checks by observations for meridian at every 5 miles or so with the correction for convergency applied (see paras. 108 and 119).

218. **Stations.**—The stations may be marked on the ground by large pegs, about 3 feet long, driven well in. If their future identification is an object, and there is a chance of the pegs being destroyed or removed, a *ghurrah* or earthen vessel filled with charcoal, buried at some depth below the surface of the ground, will give the means of finding their sites again with sufficient accuracy for all practical purposes. The surest way, however, is to note their distance and bearings from any easily recognized and permanent objects, which are not likely to be disturbed, if such should be found sufficiently near for the purpose. It will be found most convenient to fix all stations on mounds or rising ground.

It will be found convenient to have two descriptions of poles (*jhandis*) for setting up at stations to which observations are to be taken one for use in windy weather, mounted with a flag; the other when the air is

calm, with a small "moon" (made by covering a wooden hoop with calico), about 1½ feet diameter; as a flag when not flying free is scarcely more distinguishable at a distance than the bare pole. On the Revenue Survey, poles painted in foot lengths, white and black alternately, are employed, which makes them visible at a far greater distance than the common uncoloured bamboos.

All bearings taken with the theodolite should be noted to the smallest portion of a degree, its graduation will admit of; for, although they cannot be plotted nearer than to a minute, close observations are necessary to ensure accuracy in a long line of survey. Bearings should be taken to all well-defined objects, such as spires of temples, &c., wherever visible; though possibly useless for the special purpose of the survey, they may be of importance hereafter in giving the means of joining on other surveys to any of the traverse stations.

The angles on the side surveys may be taken with a good compass, prismatic, or of any other description available; the actual bearings, as shown by the instrument employed, being entered in the field-book *i.e.*, no correction being made *in the field* for the variation of compass (if any). Villages should be traversed round, so as to determine their outer limits, but no interior survey is required. These should be connected with points on the main line of traverse; the correctness of the junction line may be tested by observing from several points on it to some objects in or near the village (such as a large tree, house, &c.,) which has been well connected with the boundary survey of the village.

As the choice of a good line and the actual lining out on the ground very much depends on the accuracy of the map, this should be placed beyond a doubt, if possible, before the line is chosen and marked on it. The time occupied in taking check observations and measurements in the field will be well repaid by the facilities afforded to the subsequent work by a really accurate plan of the country.

The position of the actual watershed near the line of traverse should be carefully ascertained and noted on the map.

To the above may be added a list of the maps and drawings generally required in an engineering project.

219. **Road**—(1). *General map of country.*—The plan sufficiently broad to show the greatest amount of likely deviation. The scale of the plan will of course vary with the length of the road, but, as a rule, should not be less than 1 mile to 1 inch.

The road should be laid down on this plan, which should show the lines and cross lines actually levelled, and as many reduced levels as

convenient without crowding the plan. The positions of the benchmarks must be shown and numbered, and a sketch of the bench-marks showing, where the staff rested, should be added in the margin (see para. 155).

(2) *A longitudinal section* along proposed road.—This should show the natural surface of the ground, and that of the proposed road, and also in columns just below these surface lines, the depth of cutting or height of embankment. If the ground is level, the horizontal scale may be similar to that of the general plan, and the reduced levels entered at every 1,000 feet. The vertical scale should be at least 10 times the horizontal scale (see para. 155).

If the ground is at all undulating, the horizontal scale should be adopted so as to show reduced levels at every 100 or 200 feet. The sections should also show the villages it passes through, the kind of cultivation, and the bearings of the different parts of the road written over their respective portions, so that, in case the plan is mislaid, the section may in a manner supply its place. The height of water in wells, and highest flood lines of all water-courses, should be carefully entered. The stations should be numbered so as to correspond with those on the plan, and the horizontal distances should be marked.

(3) *The principal cross sections.*—The same remarks apply.

(4) *Half section of road when in enbankment,* showing the positions and widths of the metalled and unmetalled parts, the side slopes, drains, fencing (if necessary), &c.

Half section of road when in cutting, and complete section when partly in cutting and partly in embankment; both of these showing similar details.

(5) *Bridge site plan.*—If a river has to be bridged, a plan to a large scale of the course of the river for a considerable distance on both sides of the bridge site must be made so as to show *why* that site has been chosen in preference to any other.

(6) That part of the longitudinal section showing the passage of a river and the low land on either side, must be again drawn to a much larger scale, so as to show all the reduced levels. Any steep ascent or descent should also be shown on a large scale.

(7) Plans and sections of all *bridges* and *culverts* necessary; and these again must be accompanied by drawings of detail to a much larger scale.

(8) Plan, section and elevation of an *inspection bungalow* and *storehouse* for tools, &c.

220. Canal.—The plans for a canal project will be similar to those for oad with a few additions,

The survey should be of a scale not less than 4 inches to the mile.

In the longitudinal section, the line showing the surface of the water will be shown, as well as the line of the bed of the canal.

Besides the above-mentioned drawings, there will be required plans and sections of the lock channels, the lock gates, main and minor distributing channels, dams, falls, inlets for surface drainage, escapes for the passage of flood waters, aqueducts, bridges, &c.

It would be impossible to give the full details of the operations required for the preparation of projects for canals and railways in a general Manual on Surveying, without unduly increasing the scope and expense of the work. Directions for the guidance of surveyors engaged on such highly technical work, will be found in the publications specially devoted to these subjects.

221. **Railway***.—The drawings for a railway project are similar to those for a road. Besides, however, there will be required detail drawings, to a large scale, of the permanent way and of the rolling stock. Plans and sections, &c., of the stations, sheds, engine house and water tanks will also have to be provided.

SCALES.—The following scales will be found very convenient for all maps and plans, and are generally used in the Public Works Department :—

For general maps—

Two or four miles to the inch.

For maps accompanied by sections—

According to the amount of detail required.

Map one inch to a mile—Index plan and section.

100 feet to the inch vertical.

Detail plans and sections.

400 feet to the inch horizontal.

40 „ „ „ vertical.

For all plans of buildings, the scale will be either $\frac{1}{50}$, $\frac{1}{100}$, $\frac{1}{200}$.

222. **Useful Hints.**—The following hints may be found useful :—

1. When series of levels are taken over a tract of country, the plan and section of such levels should correspond exactly. If the scale is not too small, the measured distances between stations should be shown in *both*; the numbers of the stations, as shown in the field-book being given at every 5th station on the plan and section, with the reduced levels written on the plan in red ink. The situations of bench-marks should be

* See rules for the Preparation of Railway Projects issued by order of the Government of India.

shown accurately on the plan, and the reduced levels written clearly showing to what exact spot the numbers refer. Wherever the scale admits of it, the information given on the plan should be so full and complete, that the sections can at any time be drawn out from it alone; and, if the bearing of the different lines be written on the section, the plan may conversely be laid down from the sections alone.

2. Where a line of levels crosses a water-course, the reduced level of the bed of such water-course should be shown—that of the water surface (the date of observation being given)—of highest and ordinary flood mark, if discernible—and that of the top of the bank; and all these reduced levels should be shown on the plan.

3. The bubbles of levels should always be graduated, but as this is not invariably the case when turned out by the maker, it may be useful to know that scratches can be made on the glass with a fine file; this must be done very carefully, with a light hand, as the glass is exceedingly thin. If this is not done, a small paper scale should be affixed to the bubble tube.

4. In levelling, the staff, unless when placed on a bench-mark, or a pucka road, must always be held on a wooden peg, about 3 or 4 inches long, driven in flush with the surface of the ground; without this no confidence can be placed on the accuracy of the work.

5. The level, if it not absolutely impossible, should invariably be set up equidistant from either staff: errors of adjustment being thus completely obviated. If otherwise, it is to be borne in mind that when the line of collimation and the large bubble are in adjustment with each other, although not so with reference to the axis of the instrument, a correct result is obtainable by bringing the bubble horizontal at each sight.

6. The ordinary distances from the level to either staff to be in even hundreds or half hundreds of feet, not aliquot parts of miles.

7. All observations for level *without exception* must be connected with some point of which the reduced level (from the common datum) has been previously, or will be, ascertained. Sections of rivers, nalas, &c., to be thus connected.

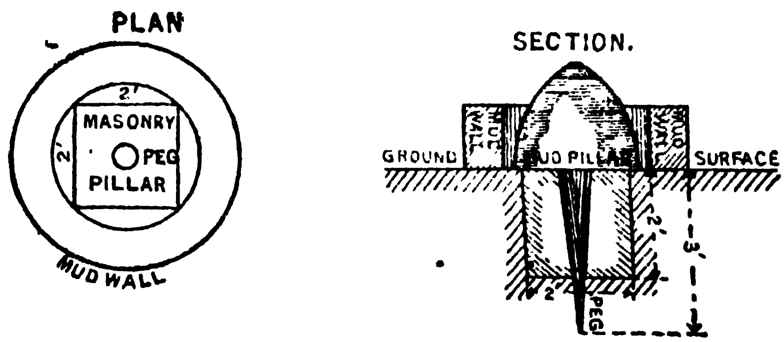
8. In *line* levelling, it will be found the simplest mode and least liable to errors to record collateral observations separately from the line series in the field-book. Such observations should be taken and recorded with reference to stations on the line.

9. Measuring chains (100 feet) should be kept of the exact length even for ordinary surveying or levelling. Their length when new

should be verified daily, every new chain stretching considerably at first. With a chain of good material some time in use this elongation is scarcely perceptible.

10. **Bench-marks.**—Invariably on masonry buildings, or other *permanent* structures. In the choice of their positions, security from injury and facility of identification are the points to be chiefly looked to. The sills of niches in, or plinths of masonry buildings are very suitable. In a well, the small niche (or *namah*) usually left for a slab engraved with the owner's or builder's name, if the sill be flat and even, is a very safe place. Where it is necessary to build a pillar for the purpose, some retired nook or waste land should be chosen as the site: the pillar, of masonry in lime cement, may be of this form—

Fig. 106.



A wooden peg about 3 feet in length being inserted in the centre of the masonry the top flush with its upper surface, on which the levelling staff is to be held. To secure the pillar from injury, a mud wall may be built round it, or a mud pillar over it, or both. To protect the wooden peg from injury by dry rot or white-ants, it should be soaked for four days in a solution of 1 lb. of sulphate of copper (*nila tutiya*) to 4 gallons of water, and should be coated with tar.

11. As bench-marks are intended for future reference, they are perfectly useless unless such a description of them be given as will serve to identify them indubitably. In addition to a sketch, the position with reference to well defined and easily seen objects in the neighbourhood, and to the north point, the name of the village in whose lands it is situated; if a tomb, the name of the person buried there; if a well, names of owners and local appellation (if any); if a boundary mark (none but those at the intersections of more than two village boundaries should be taken), the names of the villages whose lands meet there; should all be noted in the field-book.

12. All *observations* and information connected with either survey or levels should be entered in the field-book *at the time of noting in ink in the field*. Nothing should be trusted to memory.

13. The date of the survey, as well as the number and maker's name of the instrument in use, should never be omitted.

14. The north and south line should be drawn through the centre of a plan and be as long as possible. The magnetic meridian should not only be marked on the plan, but the amount of variation (and date of observation) also should appear on the face of the plan.

15. Field-books should be checked and reduced levels inked in at the conclusion of each day's work—the survey should invariably be plotted from the *original* field-book. If a fair copy is made it should be as a duplicate only in case of accident to the original, but any surveyor making a fair copy to be plotted from it on the pretence that the original is too dirty to be sent in, should meet with no mercy.

16. Field books should be properly indexed and work should have as many cross references as are necessary.

223. **Demarcation.**—Although hardly partaking of the nature of a regular survey operation, the system described below, of recording in a graphic manner the relative contour of the surface of the ground and other details, is well worthy of the attention of surveyors engaged in irrigation or drainage works in cultivated tracts of the plains of India.

The system is only applicable to cultivated tracts, as it is a graphic systematic record of the knowledge of the cultivators of the ground, modified and possibly corrected now and then by the experience of the surveyor or observer. The object with which demarcation observations are started in any tract is to prepare on a large scale, a map or chart showing the following:—

(i) The exact lines along which drainage flows off the fields, and eventually finds its way to the rivers on either side.

(ii) The exact positions of the watersheds dividing these drainages.

(iii) The areas and distribution of the main qualities of soils.

(iv) The areas and positions of the "command" of wells or other sources of irrigation which it is desired to preserve or prevent interference with.

(v) The actual position of level pegs, or other survey marks, and of the land occupied by works about to be constructed.

It will be evident to all concerned in such operations that if the above-mentioned minute information can be cheaply and accurately acquired

the calculations of discharge off catchment areas, discharge required to irrigate certain lands, or to pass down distributaries and canals, will be rendered simple and precise, and that it will be possible to carry out the alignments of channels with more accuracy and certainty than is likely to be the case with the most detailed contour survey founded on lines of spirit levelling.

The procedure is simple enough. Two copies are made of the map *(shajra)* of each village contained within the area to be demarcated: both copies are on cloth *(latta)*, one on a separate sheet and the other on a large sheet, joined up at the boundaries with copies of the maps of all villages within the tract. It may be mentioned that when large tracts of country are dealt with in order to keep the large sheets of convenient size, it will be necessary to trace the maps according to minor doabs.

These *shajras* are generally printed on a scale of 16 inches to the mile or thereabouts, and show the field boundaries and numbers, village sites, roads and tanks, and other important features. After being copied on cloth these features should be suitably colored up on both copies, and then from the written village record (or *khasra*) the various qualities of soil can also be colored up, as the numbers of the fields given in the *shajra* and *khasra* are the same there is no difficulty in doing this, indeed all through the *shajra* should be looked on as a graphic index to the *khasra*. After soils, the irrigation of wells and other sources can be shown on the map from the village season or other records, the results of one or a series of years being taken according to the degree of accuracy aimed at. Regarding the record of possible irrigation from, or command of wells and other sources of supply, it may be noted that very few sources except good wells and canals can be considered permanent, and that the record on the map of a canal project of any existing irrigation but that from good wells, is hardly necessary. To obtain the proper command of a well the results of three years' working at least should be plotted, and a thick boundary line should be drawn round this area, including any dry fields surrounded by irrigated fields.

It will save time to plot all the above information on the separate *shajras*, as a large number of men can then be employed extracting and plotting figures, it only takes a short time to trace the areas once plotted on to the large sheet.

The small sheets are now ready for out-door work. The surveyor therefore, provided with the *shajra*, should visit a village, and having enlisted as his guides a few respectable cultivators, should enquire the

direction of flow of rain water off the fields he is standing on; noting the reply, he should walk on until he finds a point from which the water divides or flows in opposite directions—this is clearly a point on a watershed, and should be marked on the map with a pencil thus, X. In the same manner the points on drainages can be determined and marked with arrows, →*viz.*, the points where the rain water from two or more fields meet, and flow off together. When a few points on watersheds or drainages are once fixed it is easy enough to walk along and mark the lines, being careful to follow the information given by the cultivators in preference to judging by the eye. By the time most of the village area has been traversed the map will be ready to have the junctions of watersheds and drainages filled in, and this should be done with great care and after due local enquiry.

A portion of a demarcated sheet, reduced from 16 inches to 6 inches to the mile, is shown on *Plate* XIX. The marks made on the separate village sheet have been colored red for watersheds and blue for drainages; the different qualities of land are shaded instead of being colored as they are in the original; the demarcation of the command of wells is omitted to avoid confusion.

The complexity of the drainage system will be noticed. The tract is part of the district of Saharanpur in the N.-W. Provinces, and an average sample of the class of country met with in the plains of India. The map, however, proves clearly enough that spirit levelling operations alone are insufficient to determine the full detail of country, though to make the map thoroughly practical and useful, the tract should be cross sectioned, and the main watersheds and drainages levelled up: as this is being done the leveller should be followed by an assistant to mark the portion and reduced level of the pegs on the map.

The work described above may be considered troublesome and expensive, but this is not found to be the case in practice, as men of ordinary intelligence on small pay can be taught the work easily; at the same time it must be remembered that, to secure accuracy, it will be necessary to provide for the clerical check of all the works carried out.

CHAPTER X.

FERROTYPE AND OTHER PRINTING PROCESSES.

224. THE Ferro-prussiate, positive Cyanotype Ferro-gallate, and other printing processes are employed for the copying of plans, patterns, or other drawings, and consist of printing the required design on sensitised paper or cloth, by the transmission of light through the design, by the methods explained.

Prints by these processes may be said to be permanent and to be unchangeable by light or damp.

Ferro-prussiate Process.

(White lines on a blue ground.)

METHOD OF SENSITISING THE PAPER.

225. The following solutions have been found to give satisfactory results:—

1.	Ammonia-citrate of iron (ferric salt) ...	100 grains.
	Water	1 ounce.
2.	Potassium ferricyanide (Red Prussiate of Potash) ...	70 grains.
	Water	1 ounce.

The solutions nos. 1 and 2 will keep good for a long time, but should be stored in the dark. Mix equal parts of the two solutions immediately before use, and apply the mixture to one side of any suitable paper by means of a sponge, or large flat brush. The sponge, which will be found more useful for the purpose, should have an even surface; if it is not even, the sponge should be cut with a knife or scissors to bring about this result, so that the surface may bear uniformly on the paper.

Charge the sponge as full as it will hold of the mixture, and apply the solution liberally to the paper for about two minutes, which time may be more or less according to the seasons. In the hot dry season a longer application is necessary, about three minutes; during the rainy season a less time is required, generally about one minute. Cover the surface of the paper rapidly with the solution, using long, free, light strokes of the sponge, working in one direction, until the surface is covered; then go over the whole surface again, crossing the strokes at about right angles to those first applied; and so on, repeating the operations until the paper has had a liberal application of the mixture. Now take the sponge nearly full

and drag it, without applying pressure, over the surface of the paper, using long strokes to remove the surplus solution, yet leaving a thin film of it on the paper, the object being to obtain as even a coating as possible.

During the operation of coating, the paper should be pinned down on a drawing board or other flat surface; when the coating is finished, the paper is hung up to dry in a dark room and should not be used till it is thoroughly dry.

When using any hard, smooth-surfaced paper, the operations of coating and drying may be repeated several times. By this means a very deep blue ground in the finished print can be produced.

Owing to the excessive dampness which pervades everything during the rains, special care should be taken during this season in preparing and storing sensitised paper. Before the paper is sensitised it should be well dried over a charcoal fire or stove to expel all dampness, after which the sensitising solution is immediately applied. This is to be done in the manner already described, but in this case, should be carried out as quickly as possible, to prevent too great a penetration of the sensitising solution in the pores of the paper. After sensitising, the paper may be dried over a charcoal fire or stove, or may be hung up to dry in a room in which a charcoal fire is burning. Immediately the paper is dry, it should be stored for subsequent use in a cylindrical tin box with a "take-off" lid, round which should be placed an india-rubber band to exclude air and moisture, and the box should always be kept in a dry place. In damp weather the sensitised paper should be dried over a charcoal fire before putting it into the printing frame.

The paper, when freshly prepared, should be of a yellowish orange, but will change to a blue colour by keeping. By adding a small quantity of gum arabic or of dextrine to the mixed sensitising solution, and also bichromate of potassium in the proportion of 2 grains to each ounce of the sensitising mixture the printing qualities of the paper remain intact, and the paper will not change colour for some time.

The Ferro-prussiate paper of commerce is generally of a bluish tint. This, however, does not impair the printing qualities of the paper to any appreciable extent, but the prints prepared on it will require a more prolonged washing, than if made on freshly prepared paper.

Printing.—Open the pressure frame and lay the tracing, drawing downwards, on the glass of the frame, and over it a sheet of the sensitised paper with the prepared side in contact with the back of the tracing. Over the paper lay a pad of felt, or some sheets of clean, smooth paper, which should have been previously dried in the sun, or over a fire, and with both hands carefully smooth the pad outwards from the centre. Then put in the back-board of the frame, care being taken that the paper

below does not slide one way or the other, and close the cross-bars. *If the* frame has more than two cross-bars, the centre bar should first be closed and then the side ones. Unless the glass, tracing, and sensitised paper are in close and uniform contact all over, it will be impossible to obtain sharpness in the finished print. The frame is then taken outside and exposed to the direct rays of the sun, which should strike the glass face perpendicularly. If the paper is fresh and dry and the sun bright, from 6 to 8 minutes, during the cold season, will be found sufficient. After the rains, when the sky is clear and the light very intense, the exposure will vary from about 3 to 6 minutes; but at first it is recommended to make exact observations till the right length of time to expose has been ascertained. This can be done by trying different exposures on a small slip of sensitised paper: expose one-half for about 4 minutes, the other half being covered over so that no light acts on it. Now uncover the unexposed half for about 6 minutes, and cover over the exposed half. After this has been done the paper is removed and washed in several changes of clean water, when the distinctness of the lines and the strength of the blue ground will indicate which half of the slip gives the better result. This will be a guide as to the exposure required for the large sheet.

Assuming that the correct length of time for exposure has been determined and that the paper has been exposed, then quickly take it out of the pressure frame and float in a dish or tray of clean water, moving it rapidly from side to side, and changing the water several times till the water is no longer tinged with yellow, and the drawing shows out in clear lines, after which the drawing is hung up to dry.

Any paper will answer for this process, but the best results have been obtained on papers "Nos. 50 and 51," specially prepared for this purpose by Messrs. Schleicher and Schull, and obtainable from Messrs. Treacher & Co., Bombay. Good results have also been obtained on ordinary lithographic paper obtainable from the Government Stationery Office, Calcutta. The latter paper is very much cheaper than that of Schleicher and Schull, and the results are nearly as good. With these two brands of paper the lines show out of a pure white or bluish white, while with other papers the lines are more or less of a brownish tinge.

Ready sensitised paper is an article of commerce and is prepared by Messrs. Marion & Co., 22 and 23, Soho Square, London, W., and obtainable from most of the photographic firms in this country. Marion's paper has been found to give very good results and will keep without deteriorating for a considerable time if stored in cylindrical tin boxes and kept in a dry place as before described.

Specially prepared tracing cloth may also be obtained from Messrs. Marion & Co. Prints prepared on it require from four to six times the exposure that a print on paper would require; otherwise other conditions being equal the procedure in preparing prints on the cloth is the same as for paper. When the print is dry, the slight creases in the cloth may be removed by rolling it tightly round an ordinary office ruler and keeping it so for an hour or more.

It is desirable that the drawings to be copied should be on a very translucent material such as fine white tracing paper or good fine tracing cloth, the drawings to be made with perfectly black ink in firm full lines especially the finer ones, so that they may be quite opaque. A little burnt sienna may be added to the Indian ink to give it increased opacity. Care should be taken to keep the back and surface of tracing clean and free from anything which might print through and interfere with the clearness of the drawing.

As far as possible, all lines usually drawn in colour should be drawn in black dotted lines of different kinds. However, if the use of colour in the original is compulsory, red lines should be drawn in thick vermilion; yellow lines with Indian yellow; brown with burnt umber; blue and green lines with a mixture of chrome yellow and dark Prussian blue in different proportions. All washes of colour to be avoided if possible, but where necessary they may be replaced by cross-hatching of the required colour.

If desired, coloured tracings can be copied, and, provided the coating of colour be not too heavy, fairly satisfactory prints are obtained.

Although the best results are got by copying tracings, it is possible to get quite useful results from drawings even on fairly thick drawing paper, a very long exposure being given to compensate for the opacity of the paper.

Where the process is regularly used in workshops, &c., in England, it is a common practice to omit the inking in of the drawing on drawing paper, and to make a tracing on very transparent tracing cloth to serve as the standard drawing to be kept in the office. This tracing then serves for the reproduction of blue copies for the shop, &c.

White lines, figures and printing may be taken out of a drawing or obliterated, by going over them with a pen charged with a solution of Prussian blue mixed to the depth of colour required.

Additions in white of lines, figures, or printing may be made with a clean pen dipped in a solution of—

Oxalate of potash	150 grains.
*Saturated solution of gum	40 minims.
Water	1 ounce.

*The function of the gum solution is to give consistency to the mixture and so prevent spreading of the lines and figures.

After applying the solution, wait till the lines, figures, or printing are quite white and clear; then blot off with a piece of clean blotting paper and immerse the print rapidly in clean water and wash it well, changing the water a few times.

In applying the solutions given in page 1 to sensitise the paper the fingers become discoloured. These stains can be removed by applying a little of the above solution without the gum arabic: rub the solution over the fingers till the stains disappear, after which the hands should be well washed.

This solution may be conveniently kept in a wide-mouthed bottle, large enough to be able to dip the fingers into.

The pressure frame required will be similar to those used for ordinary photographic work, and should be large enough to take the largest tracing or drawing required. The front will have a piece of good, thick, clear plate glass, and the back will have a board, which should be jointed in two, three, or more pieces, according to its size, and have cross-bars and springs to correspond to the number of joints. A piece of felt or thick flannel should be cut to the size of the frame and kept with it, or in place of the felt several sheets of clean soft paper may be used.

The glass of the frame should be kept clean on both sides and free from scratches, and the felts or paper pads should be thoroughly well dried in the sun, or over a fire, before use.

Pressure frames of any required size are made up in the Canal Foundry and Workshops, Roorkee. The cost of a frame suitable for drawings up to 30″ × 22″ is about Rs. 16. Good plate glass ¼-inch thick, and of various sizes, can be procured in the Fatehpuri Bazar, Delhi, or at Calcutta. A piece measuring 30″ × 22″ × ¼″ can be had for about Rs. 10, and the charge is proportionate for the other sizes.

A pressure frame as described may not always be to hand. In such a case the following method answers well :—

Take a drawing board, or any flat board with a fairly even surface, and on it place a piece of any sort of soft cloth neatly folded so as to give a thickness of about an inch, the cloth to be free from lumps or irregularities, and when folded to be somewhat larger than the drawing to be copied. On the cloth, place the prepared paper with the sensitised side upwards; on the paper, place the tracing or drawing with its face upwards; and over the whole, place a piece of good plate glass, a little larger in size than the drawing it is desired to copy; the object being to bring the prepared paper and drawing into close contact with each other, and to keep them in one position during exposure. The weight of the glass supplies the pressure, and the cloth, being soft and yielding, is pressed against the glass plate and into any inequalities that may exist, bringing the prepared paper and

tracing with it, and thus securing the contact required. A small strip of wood might be put round the board in the form of a ledge to prevent the glass from sliding when it is tilted to bring the plane of its surface at right angles to the sun's rays. If the paper and tracing are in perfect contact, tilting the board is not of much consequence. Good results have been obtained when the board has been in a nearly horizontal position, but if the board be not tilted towards the sun a longer exposure will be required. The correct length of time may be ascertained by means of a small slip of prepared paper, as already described.

Dishes or trays, three or four inches deep, for washing prints, may be of porcelain or of strong sheet zinc or tin, and should be a little larger in size than the largest print. It is recommended to coat the inside of the tin or zinc trays with black Japan varnish obtainable from any general merchant, or with ordinary shellac varnish (shellac 8 oz., methylated spirit 1 pint). The varnish to be removed occasionally as required, and to be applied to the trays with a brush, like a coating of paint. Trays made of tin will last better if the varnish be applied all over the inside and outside surfaces.

A flat board or ordinary drawing board will be required for sensitising the paper; also some drawing pins, to keep it in position while being coated with the sensitising solution; a fair-sized sponge to apply the solution; some wooden clips to hold the paper while drying; a graduated 4 oz. measure for solutions; and a small set of scales and weights for weighing chemicals.

Defects in Ferro-Prussiate Prints.

226. *When the print is weak-looking, with the back ground rather a light blue, but lines clear.*—We conclude that the print is under-exposed. Try another print and give a longer exposure; or if the defect is not very marked, immerse the print for a few minutes in the following weak acid solution—10 drops of hydrochloric acid to 10 oz. of water; or 100 grains citric acid to a pint of water. This intensifies the blue ground and the white lines show clearer by contrast. Another method, and one which gives better results, is to immerse the print for a short time in a bath of 20 grains of soda to one quart of water. The print should be left in this bath only just long enough to change the blue ground to a deeper blue, after which it should be at once removed and quickly immersed in a tray of plain water (to stop the further action of the soda), and then well washed, the water to be renewed several times. When the print is put in the soda bath the lines become clearer and the blue ground rapidly intensifies up to

a certain point after which it begins to lose its blue colour and gradually changes to a light yellowish colour. Care therefore should be taken to remove the print from the bath when it is judged that the maximum depth of blue colour has been reached.

Ground of print of a very deep blue colour, but lines not clear and of a bluish tinge the fine lines of the original drawing very indistinct and broken, or not seen at all.—Print has been over-exposed. If these defects are very decided, reject the print and prepare another, giving less exposure. If not too decided, the print may be reduced by prolonged washing in several changes of water, and then immersing it in the carbonate of soda bath given above, till the desired reduction has taken place, after which the print is washed in several changes of plain water.

Print weak and having a somewhat 'sunk-in" appearance ground of a dull blue colour, with lines rather indistinct and of a yellowish brown.—This is due to dampness owing to insufficient care in preparing, drying, or storing the paper, as already described. *See* remarks on preparing and storing paper during the rains, page 2.

Print generally clear and well defined, but at places the lines blurred and of a bluish colour.—This arises from imperfect contact between the sensitised paper and tracing. Place the sensitised paper carefully in position and avoid crumpling it, as the tracing and prepared paper should be perfectly smooth and even.

Streaks of white and white spots in the blue ground of print.—These are due to want of care in coating the paper with the sensitising solution. If the solution be applied liberally as directed, the whole surface of the paper covered with it, and the excess solution removed carefully, these markings will not show.

Markings in print corresponding to the form of the finger tips.—These are due to handling the sensitive surface of the paper when the hands are in a heated state. The remedy in this case is obvious; the sensitive surface should be touched as little as possible with the fingers.

Ground of print of a light blue colour and lines of a light bluish tint when it is known that the print has not had more than the normal exposure to sunlight.—This is due to the sensitised paper having deteriorated by keeping, or the paper may have been exposed to white light, which would occasion a blue deposit over the whole surface. Nothing can be done in this case: the print will show a want of force and brilliancy due to the blue deposit on the lines, which in good, fresh and properly prepared paper would be of a pure white.

Positive Cyanotype Process.

(Blue lines on a white ground.)

227. Paper specially prepared for this process is an article of commerce, and can be had from Marion & Co., 22 and 23, Soho Square, London, W. It will be found more convenient to purchase the paper ready for use than to prepare it. Without proper appliances and practice it is difficult to get an even coating.

If, however, it is considered desirable to prepare sensitive paper for this process, hard and well-sized paper should be selected, so that the sensitising solution may be kept, as far as possible, on its surface. Good ordinary drawing paper is suitable, also Rives' or Saxe paper generally used for photographic prints, but the papers nos. 50 and 51 by Messrs. Schleicher and Schull, already described, have been found to give the best results.

The following solutions are required for sensitising the paper:—

	A	
Gum arabic	1	oz.
Water	5	,,
	B	
Ammonia-citrate of iron	1	oz.
Water	2	,,
	C	
Perchloride of iron	1	oz.
Water	2	,,

Solution A can only be kept for a few days; solutions B and C will keep for several weeks in well-stoppered bottles. When required for use, they are mixed together in the proportions of 20 parts of A, 8 parts of B, and 5 parts of C, and in the order given, or the gum will be coagulated. Should this occur, the mixture may again be rendered liquid by the addition of a few drops of glacial acetic acid.

Sensitising the paper.—This operation and all the subsequent ones, except the exposure to sunlight, must be performed in a room illuminated by yellow light passing through one or two thicknesses of yellow paper or calico fastened over the windows, or by candle or by weak lamplight. The paper is pinned down to a drawing board, and the solution applied as described for sensitising paper in the Ferro-prussiate process, only more care has to be exercised; the coating to be as even as possible, so as to avoid streaks. It is important that the paper should dry quickly, so that the solution may not sink into its substance. As soon as the paper is dry, it will be well to put it away carefully in an air-tight tin case.

Exposure.—The exposure will vary with the intensity of the light. In direct sunlight from 15 to 40 seconds will be found sufficient; in the shade or dull light from 1 to 5 minutes; in rain from 5 to 15 minutes and in dull foggy weather as much as from 15 to 30 minutes or longer may be required. By practice one soon learns to guess the proper exposure under ordinary conditions of working.* It is important, however, that in this process the exposure should be exactly right, and therefore, unless the exact time required is known from past experience, it is advisable to try different exposures on a thin slip of sensitive paper in the manner already described for Ferro-prussiate prints.

Development of the print.—This operation must be performed in yellow light. The developing solution to consist of a saturated solution of ferrocyanide of potassium.

A sufficient quantity of the solution should be poured into a dish or tray so as to fill it to a depth of about an inch. Before commencing to develop, the print is laid face downwards on a table, and the edges turned up carefully with the aid of a straight-edge, so as to form a sort of tray about 1-inch in depth. The copy is now floated face downwards on the developing solution; the turned up edges prevent any of the solution from getting on the back of the copy, which would cause blue stains to appear. Any air bubbles must be removed by quickly lifting each of the corners of the copy in turn by one hand and gently lowering it again, the other hand being used at the same time to drive out the air bubbles from the centre. After floating the copy on the developing solution for about half a minute, remove it carefully, hold it up, and allow the action of the developer to continue but only so long as the yellow ground remains free of blue spots. The longer the film of prussiate can be kept on the print, the stronger and darker will the lines come out. As soon as any sign of a blue spot begins to show, immerse the print at once face downwards in a tray of clean water, and wash it in several changes.

After washing, immerse it in a bath of hydrochloric acid, 1 ounce to 10 ounces of water; keep it in this bath from 5 to 10 minutes, after which remove and place it face upwards in a tray of clean water, and well wash and rub the surface with a sponge to remove the blue mucilage; then copiously flush with clean water. The lines of the copy will now be found to stand out blue on a clear white ground.

For the developing and acid solutions trays of lead in wooden frames will be required; the inside of the trays to be coated with Bates' black photographic or shellac varnish, the coating to be renewed as necessary.

For washing the print, trays as described for the Ferro-prussiate process will answer.

Causes of Failure.

228. *The ground appears blue.*—This arises from under-exposure to the light, or from the print having been kept too long exposed to the action of the developing bath.

The ground remains white, while the lines are broken and pale.—This may be due to over-exposure, or to the lines of the tracing not being sufficiently opaque to stop the passage of light through them.

When the print is put in the acid bath, the lines turn a dark blue which washes off when being brushed.—This arises from insufficient development in the prussiate bath. If the ground is also spotted blue it is due to under-exposure.

To obtain prints showing blue lines on clear ground by modification of the ordinary Ferro-Prussiate Process.

229. Place the drawing or tracing to be copied with its back against the glass of the printing frame ; then place over the drawing or tracing a piece of prepared sensitised tracing cloth with its sensitised surface down against the face of the drawing ; close the printing frame and give a prolonged exposure to light the exposure to be three or four times longer than would be required for an ordinary ferro-prussiate copy.

After exposure proceed as described in the ferro-prussiate process. When dry the print may be treated with a weak solution of carbonate of soda to intensify the blue ground and clear the lines after which it should be well washed and hung up to dry. When dry, roll the print round an ordinary office ruler the object being to remove all creases from the cloth.

When the copy is smooth and even place it in the printing frame with its back against the glass then place a piece of sensitised paper or cloth with the sensitised surface down on the face of the prepared negative copy and operate as already described for obtaining an ordinary, ferro-prussiate print. As the light is passed through a negative copy a positive print—one shewing blue line on a clear ground—will be produced.

Instead of preparing the negative copy on tracing cloth, paper may be used; the paper print can be made transparent by rubbing it over with vaseline, or by applying a mixture of one part castor oil and five parts spirits of wine.

Ferro-Gallate Printing Processes.

230. *(This process is useful in the reproduction in black lines on a clear ground of fac simile copies of drawing plans and tracings.)*

Paper.—For this process a hard well-sized paper is indispensable. Schleicher and Schull's papers Nos. 50 and 51 obtainable from Messrs. Thacker & Co., or from Messrs. Treacher & Co., Bombay, answer fairly well and are the best of their kind for this purpose to be had in India.

Developing Trays.—Trays for developing should be made of wood lined with sheet lead, the lead to be protected with a coating of black Japan varnish. Trays of zinc or tin protected with Japan varnish answer fairly well but the acid solution when not in use should not be kept in the trays but should be stored in an earthenware vessel.

For washing purposes zinc or tin trays are quite suitable.

Sensitising the papers.—This operation must be carried out in a room illuminated by yellow light passing through one or two thicknesses of yellow paper, or cloth fastened over the windows, or by candle, or weak lamp light. The following formulæ are recommended for sensitising the paper, either No. 1 or No. 2 may be used :—

No. 1.

Water	15 ounces.
Gelatine	[illegible] ounce.
Perchloride of iron	1 „
Tartaric acid	[illegible] „
Persulphate of zinc	[illegible] „

No. 2.

Water	40 ounces.
Gelatine	1 ounce.
Perchloride of iron (solid)	2 ounces.
Tartaric acid	10 drams.
Ferric sulphate	10 ..

The paper is laid smoothly down on a drawing board, glass plate or other flat surface and should be fastened down on two sides with pins or clips.

The sensitising solution is applied to the paper by means of a fine sponge, which should be passed lightly over the paper, up and down and across, taking care to equalise the coating as much as possible, and to avoid streaks or other markings. Before applying the sensitising solution it is advisable to dry the paper over a charcoal fire or stove to expel all dampness, after which the solution should be immediately applied. It is important that the sensitised paper should dry quickly so that the solution may not sink into its substance, it should, therefore, be hung up to dry in a room in which a stove or charcoal fire is burning.

This of course would not be necessary in the hot dry season. When thoroughly dry the sensitised paper should be stored for subsequent use in a tin cylindrical box with a take-off lid, round which should be placed an india-rubber band to exclude air and moisture.

Exposure.—The exposure to sunlight is about the same as for ferro-prussiate prints, that is, from 5 to 10 minutes according to the intensity of the light. To ascertain if the exposure has been sufficient, open the pressure frame and lift up one corner of the sensitised paper, if the greenish-yellow tint has disappeared, except where covered by the lines, it shows that the exposure has been sufficient, and the print should be removed from the pressure frame.

Developing.—This operation must be carried out in yellow or red light. The copy is floated face downwards in the following solution :—

Gallic acid	1 ounce.
Oxalic „	5 grains.
Methylated alcohol	10 ounces.
Water	50 „

Care is to be observed in floating the paper. Hold two opposite corners of the paper, and bring the hands nearly together, a convex form is thus given to the sheet, the middle of which should first touch the solution, the corners held by the hands to be gradually brought down till the sheet floats on the liquid. The formation of air bubbles is thus prevented; should, however, any be formed they can be removed by the aid of a glass stirring rod.

The copy should be allowed to remain on the solution till the lines show up clear and black. It is then removed and washed thoroughly, and, if necessary, the surface rubbed with a soft sponge to remove any stains or markings, after which the print is hung up to dry.

The following can be recommended also as giving satisfactory results:—

Sensitising mixture.

A	Gum arabic	1 ounce.
	Water	10 ounces.
B	Tartaric acid	1 ounce.
	Water	4 ounces.
C	Solution of Ferric chloride, 45° Beaumè, ...	2 „
D	Ferrous sulphate	5 drams.
	Water	4 ounces.

Solution D is added to B, and the mixture added slowly with constant stirring to A; finally solution C is gradually added stirring well the whole time during admixture.

Tough smooth well-sized paper should be used. The sensitising mixture is applied by means of a brush, and the paper quickly dried by

heat. Exposure is complete when the ground of the print is nearly white, the parts protected from the light being of a light yellow colour. Development is effected by floating the print for about one minute face downwards in the following solution—

Gallic acid	1 dram.
Oxalic "	3 grains.
Water	50 ounces.

The print is then removed from the developing bath and washed well in plain water.

Ready-sensitised paper.—Paper ready-sensitised (Ferro-Gallic Paper) is prepared by J. R. Gotz, 19, Buckingham Street, London, and can be purchased from Thacker and Co., Bombay.

The following is a good developing formula for ready-sensitised paper:—

Gallic acid ..	1 ounce.
Alum ..	1 "
Water	8 pints.

The acid and alum should first be dissolved in 2 pints of hot water, after which the remaining water should be added.

To develop prints on this paper the copy is immersed in the developing solution till the drawing shows up clear and the lines black, after which it is washed and hung up to dry in the usual way.

Defects.—Over-exposure is known by the lines being faint and broken, the thick lines only to be seen while the ground is white and clear.

When the ground of the print is dark and discoloured it denotes under-exposure.

The lines after prolonged immersion in the developing solution are of a dull brown colour, while the ground is clear. This shows that the acid in the solution is nearly exhausted. Add more acid, or if, owing to a number of prints having been developed with the solution, it is very much discoloured, a fresh developing solution should be made up.

The basis on which the preceding processes are founded is that a ferric salt is reduced to the ferrous state by the action of light. Thus, taking ferric chloride ($Fe\,Cl_3$) as an example, this salt, on exposure to light, throws off one atom of chlorine and becomes ferrous chloride ($Fe\,Cl_2$). If a solution of a ferric salt be applied to one side of a smooth-surfaced paper the surface of the paper when dry will present a yellowish colour inclined to orange; if the paper be placed in a pressure frame under a transparent drawing or tracing, and exposed to sunlight for a fixed time, a change will be found to have taken place; the parts of the paper immediately under the transparent parts of the drawing or tracing will be of a light brownish colour, nearly white, while the other parts of the paper immediately under the lines will be found unchanged, and on the paper we shall have a copy of the drawing or tracing in yellowish orange lines on a nearly white ground; this is the visible change.

The chemical change is that where the light has passed through the transparent parts of the drawing to the prepared paper immediately below and in contact with it, the ferric salt on the paper has been reduced to the ferrous state in these parts by the action of light; while, owing to the opacity of the ink lines of the drawing or tracing, no light can reach the paper immediately below the lines, and therefore no change takes place, consequently under the lines we have the unchanged ferric salt. Thus, we have a ferrous and a ferric salt on the paper; the ground of the drawing will be of a ferrous salt, while the lines will be made up of a ferric salt. By applying re-agents, which act differently on these two salts of iron, this reduction is made apparent and a coloured picture or drawing is produced. Thus, if ferricyanide of potassium (K_3 Fe Cy_6) be applied, all the parts acted upon by light become blue; that is, when ferricyanide of potassium is added to a ferrous salt a deep-blue precipitate is produced of ferrous ferricyanide [Fe_3 (Fe $Cy_6)_2$], called Turnbull's blue, and the blue matter thus produced is insoluble. The ferricyanide of potassium causes no change in the ferric salt (which corresponds to the lines of the drawing or tracing), which being soluble can be washed out in water, giving a print on the paper of white lines on a blue ground. Prints thus produced are called **ferro-prussiate prints.**

Ferrocyanide of potassium (K_4 Fe Cy_6) acts on the unexposed parts or parts not acted on by light, that is, on the ferric salt, and produces with it a deep-blue precipitate of ferric ferrocyanide [Fe_4(Fe $Cy_6)_3$], which is insoluble. The ferrocyanide of potassium occasions no change in the ferrous salt, which is therefore soluble and can be washed out in water, thus giving a copy on the paper of blue lines on a white ground. Prints produced by this method are called positive cyanotype prints.

Similarly, gallic acid ($C_7H_6O_5$) or tannic acid ($C_{27}H_{22}O_{17}$) used in place of the ferrocyanide of potassium, produces a black nearly insoluble compound (ink) with a ferric salt (corresponding to the parts not acted on by light), and causes no change to a ferrous salt (corresponding to the parts acted on by light), which remains soluble and can be washed out in water, giving a drawing of black lines on a nearly white ground.

For the production of drawings giving white lines on a blue ground (ferro-prussiate prints), instead of applying a solution of ferricyanide of potassium after exposure to light as described, in practice it has been found more convenient to mix the ferricyanide of potassium with a ferric salt before exposure: the mixture is spread on a paper and dried in a dark room. It will be observed that the ferricyanide of potassium produces no change with a ferric salt, but if the paper so prepared be placed in a pressure frame under a transparent drawing or tracing and exposed to light, the ferric salt immediately under the transparent parts of the drawing is reduced to the ferrous state by the light, as already described, and conjointly with this reduction the ferricyanide of potassium acts on the ferrous salt thus formed and produces with it an insoluble blue matter, the unchanged ferric salt on the paper immediately under the opaque lines of the drawing remains soluble and washes off in water, thus giving a drawing of white lines on a blue ground.

Aniline Printing Process.

(Reproduction in dark lines on a clear ground from a Tracing.)

231. This process is dependent on the action of bichromates on organic matter, and the oxidation of aniline by chromic acid. Thus aniline salts have the property of striking certain colours when brought in contact with acidified bichromates. Sized paper is sensitised by brushing over it an

acidified solution of the bichromates of potassium or ammonium, and is dried quickly in the dark, or in a photographic dark room. The paper is then exposed to light under a tracing, and when the lines and figures are visible, is exposed to the action of aniline vapour. Those parts protected from light by the lines or figures of the tracing become deeply coloured by the action of the aniline vapour which reacts on the chromic compound not reduced by light, and causes no action with the reduced chromium salts, as these acquire a neutral reaction and will not readily assimilate bases.

Sensitising solutions.

1.	Potassium bichromate	160 grains.
	Phosphoric acid solution	2 ounces.
	Distilled water	5 ,,
2.	Amonium bichromate	160 grains.
	,, chloride	160 ,,
	Sulphate of copper	30 ,,
	Sulphuric acid	½ ounce.
	Water	10 ounces.

Either 1 or 2 may be used.

The solutions keep in good condition for a long time, but it is advisable that they be stored in the dark.

Only good well-sized paper should be used, and sensitising may be carried out by brushing or floating.

Sensitising.—The preparation of the paper may be carried out by lamp light, subdued day-light, or yellow light; but the paper must be dried in the dark, or in a photographic dark room. It will be found more economical to apply the sensitising solution by means of a brush, which should be fairly large and flat. The solution should be applied as quickly and evenly as possible so that it may not penetrate too far into the body of the paper. The surface of the paper only should be impregnated, otherwise the ground would be more or less discoloured, and the lines and figures being imbedded would not be sharp. After sensitising, the paper should be dried as quickly as possible, and should be used on the day it is prepared, or, at most, the next day, as it does not keep.

Printing.—The printing is carried out as described in the ferro-prussiate process: the paper, however, is more sensitive than ferro-prussiate paper. The print should be exposed till the lines and figures of the drawing appear of a faint yellow colour on a greenish-white ground. In bright sunlight the exposure is generally from one to two minutes.

Development.—The print is put into the bottom of a shallow box with a close-fitting lid. On the lid is fastened a piece of damp flannel, and on

this piece is attached another bit of flannel on which a little of the following developing solution is sprinkled :—

Aniline solution	1 ounce.
Benzole	12 ounces.

Development is completed in from five to ten minutes dependent on the duration of the exposure to light. The best result is obtained by a fairly long exposure and prolonged development.

When a good dark tone is produced, the print is washed in plain water and then immersed for a short time in a bath of—sulphuric acid ½ ounce, water 50 ounces.

It is again washed in a few changes of water and finally immersed for a few seconds in a bath of—liquor ammonia ½ ounce, water 40 ounces. The print is then removed, washed and hung up to dry. The acid and ammonia baths are not essential, but better results are obtained by their use.

Moisture is absolutely necessary in the development of aniline prints. Care should therefore be observed that the flannel attached to the lid of the box is thoroughly damp. Should the air in the box be dry development will not be satisfactory.

Development may also be carried out by pinning the exposed print to the lid of the box, and having the damp flannel, with the piece on which the aniline solution is sprinkled, at the bottom. Also, instead of sprinkling the developing solution on the flannel, the solution may be placed in a shallow dish at the bottom of the box, and when development is completed, the solution removed and stored for future use in a well-fitting stoppered bottle.

Ferric Chloride and Gelatine Process.

(Dark lines and figures on a clear ground from a Tracing.)

232. This process is dependent on the action of a ferric salt on gelatine, in that ferric chloride has the property of rendering gelatine insoluble.

Paper is coated with gelatine to which a pigment is added as below :—

Gelatine	300 grains.
Water	10 ounces.

The gelatine should first be soaked in half the given water until it is fairly soft, then the remainder of the water added, and the mixture stirred and dissolved by means of a gentle heat. Indian ink or any suitable pigment is then added in sufficient quantity to bring about the required colour.

The warm pigmented gelatine solution should be applied to the paper by brushing, care to be observed that the coating is thin and uniform.

The paper is then dried and should present a uniformly coloured surface.

When dry the paper is sensitised by *immersion* in a solution of—

Ferric chloride	..	..	..	..	2 ounces.
Tartaric acid	..	..	..	..	300 grains.
Water ..	..	..	..	..	20 ounces.

After sensitising, the paper is dried in the dark or in a photographic dark room. Printing is carried out as described in the ferro-gallate process: the exposure to sunlight being about from 5 to 15 minutes according to the intensity of the light.

The part exposed to light, that is, the ground of the drawing, becomes soluble in hot water, while the parts protected from light by the lines and figures of the tracing remain insoluble: hence development is effected by immersion in hot water; and a print is obtained, according to the pigment used, showing dark or coloured lines on a clear ground.

Acidified Ink Process.

(Black lines on a clear ground.)

233. Paper is uniformly and thinly coated by brushing with--

Gelatine	..	..	..	..	300 grains.
Water ..	..	..	..	..	10 ounces.

When dry it is sensitised by brushing *on the back* a solution of—

Bichromate of potassium	..	..	..	150 grains
Ammonia ..	..	..	..	½ dram.
Water	..	..	..	10 ounces.

The solution should be allowed to thoroughly imbue the paper, to effect this a second brushing should be resorted to, after which the paper is dried in a dark room. When dry it is exposed to light under a tracing in a pressure frame until the lines and figures of the drawing are well defined.

The paper is then immersed in hot water and the bichromatised gelatine not rendered insoluble by the action of light, that is, those parts protected by the lines and figures of the tracing, dissolved out, leaving bare paper at these parts.

The paper is then blotted and brushed over with—

Liquid Indian ink ..	..	..	..	..	1 ounce.
Sulphuric acid	..	..	..	..	30 minims.
Caustic potash	..	..	..	..	12 ,,

The ink solution fixes itself only on the bare paper, which represents the lines and figures of the drawing, and a copy showing black lines on a clear ground is produced.

Modified Carbon Process.

(Black lines on a clear ground.)

234. Paper is coated with gelatine and sensitised with bichromate of potassium as described in the Acidified Ink Process. It is dried in a dark room, and when dry exposed, in a pressure frame, to light under a tracing until the lines and figures of the drawing are clearly visible. The paper is then immersed in cold water and sponged, the water being changed several times to remove the chromium salt not reduced by light. The paper is now blotted fairly dry and its surface brushed over with—

Liquid Indian ink	1 ounce.
Bichromate of potash	10 grains.

After applying the solution the paper is dried in the dark or in a photographic dark room. When dry it is placed in a pressure frame, with the *back* of the paper next to the glass of the frame, and exposed to sunlight for about two minutes. The paper is then immersed in plain water, and the ground cleared by means of a hard brush or sponge until the drawing shows up in black lines on a clear ground.

The rationale of the foregoing is that in the first exposure to light under a tracing the ground of the drawing was, by the action of the light, rendered insoluble and practically non-absorbent; while the parts protected from light, which correspond to the lines and figures of the drawing, remain unchanged and absorbent; consequently the lines and figures only take up the bichromatised Indian ink and thereby become re-sensitised.

When the back of the copy is exposed in the pressure frame the light acts through and on the lines and figures, rendering these insoluble, but practically causing no action on the ground of the print, which is easily cleared by means of a sponge or brush, and thus a drawing showing black lines on a clear ground is produced.

NOTE.—The bichromates of potassium and ammonium are highly poisonous.

235. **List of Apparatus and Chemicals for Ferro-prussiate and Ferro-gallate Printing Processes with approximate cost.**

	Rs.	A.	P.
1 Printing frame of well-seasoned Mahogany, brass bound, for drawings 30″ × 22″ and under ...	17	0	0
1 Plate glass for do., best quality, size 30″ × 22″ × ¼″	11	0	0
1 Pad for printing frame, 3 thicknesses of flannel with half a quire of paper	2	12	0
3 Tin trays in wooden frame, at Rs. 3 each ...	9	0	0
12 American clips for drying paper ...	0	8	0

	Rs.	a.	p.
12 Drawing pins	0	8	0
1 Sponge, best quality	1	6	0
1 Four-ounce measuring glass	0	12	0
4 Yards of yellow cloth for windows in sensitising room	0	9	0
1 lb. Ammonia citrate of iron	2	8	0
1 lb. Potassium ferricyanide	2	8	0
1 Four-ounce bottle citric acid	0	12	0
1 One-ounce bottle Carbonate of Soda, in powder ...	0	4	0
1 Four „ „ oxalate of potash	0	5	0
1 lb. Gallic acid	4	4	0
2 lb. Alum (can be purchased locally)			
1 Roll Schleicher and Schull's paper, 55 yards long by 58½ inches wide, "No. 51"	20	0	0
Highly transparent Tracing Parchment; does not change colour; in rolls 33 yards long by 39 inches wide, per roll	18	0	0

CHAPTER XI.

USEFUL PROBLEMS IN SURVEYING.

236. *To draw upon the ground a straight line through two given points.*

Plant a picket, or staff, at each of the given points, then fix another between them, in such a manner that when the eye is placed at the edge of one staff, the edges of the other two may coincide with it. The line may then be prolonged by fixing up other staves. The accuracy of this operation depends greatly on fixing the staves upright, and not letting the eye be too near the staff from whence the observation is made.

237. *To walk in a straight line from a point to a given object.*

Fix upon some point, as a bush, or a stone, or any mark that you may find to be in a line with your given object, and walk forward, keeping the two objects strictly in line, and always selecting a fresh mark when you come within 20 or 30 paces of the one upon which you have been moving. Observe—that to walk in a direct line, it is always necessary to have *two* objects constantly in view.

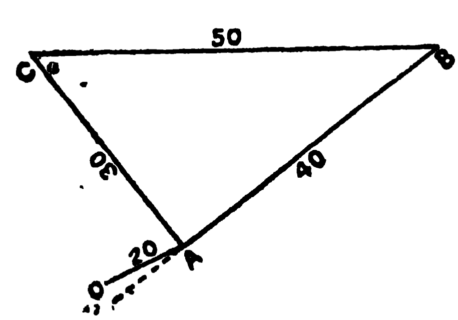
238. *To trace a line in the direction of two distant points.*

Let two persons separate to about 50 or 60 paces; then by alternately motioning each other to move right or left, they soon get exactly into line with the distant objects; or for greater accuracy, they may hold up staves.

In sketching ground, it is constantly necessary to get in line between two objects: if these are not very distant, a well-drilled soldier can always do so within a few paces (near enough for sketching purposes) by fronting one object exactly, and then facing to the right about; when if he finds himself accurately fronting the other object, he will be tolerably well in line with them. A right angle may also be formed very nearly, by fronting an object, and then facing to the *right* or *left*.

239. *To lay off a perpendicular with the chain.*

Fig. 107.



Suppose A the point at which it is required to erect a right angle; fix an arrow in to the ground at A, through the ring of the chain, marking twenty links; measure *forty* links on the line AB, and pin down the *end of the chain* firmly at that spot B, then draw out the remaining eighty links as far as the chain will stretch, holding by the centre

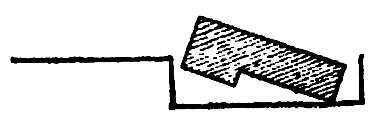
fifty-link brass ring as at C—the sides of the triangle are then in the proportion of three, four and five, and consequently CAB must be a right angle.

An angle equal to any other angle can also be marked on the ground, with the chain only, by measuring equal distances on the side containing it, and then taking the length of the chord : the same distances, or aliquot parts thereof, will of course measure the same angle. (*See* Chap. I, Prob. 2).

240. *To avoid an obstacle, such as a house in your chain line.*

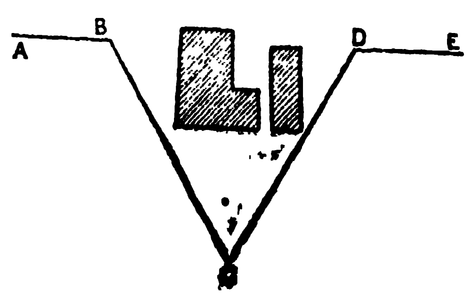
The usual way of avoiding an obstacle of only a chain or two in length, such as a house, is by turning off to the right or left at right angles till it is passed, and then returning in the same manner to the original lines.

Fig. 108.



A more convenient method is to measure, on a line making an angle of 60° with the original direction, a distance sufficient to clear the obstacle and to return to the line at the same angle, making CD=BC; the distance BD is then equal to either of these measured line.

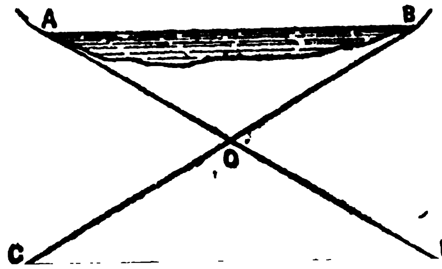
Fig. 109.



241. *To find the length of the line* AB *accessible only at both ends.*

Having fixed on some convenient point O, measure BO and AO; and prolong those lines till OC=OB, and OD=OA ; then the distance between the points D and C will be equal to AB, for the sides or the triangles COD, BOA, about the equal angles at O, are respectively equal ; therefore the third sides CD, BA will also be equal.

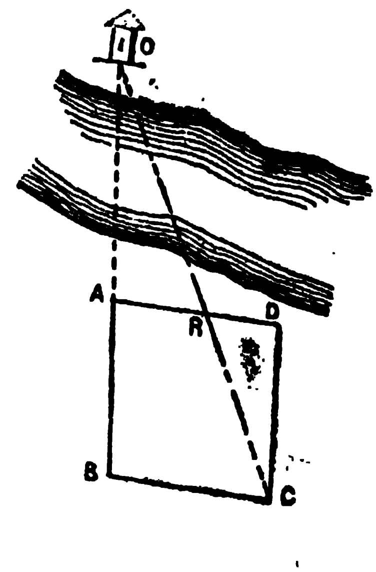
Fig. 110.



242. *To find the distance of an inaccessible object* O *by means of a rhombus.*

With a line or measuring tape, whose length is equal to the side of the intended rhombus, lay down one side BA in the direction BO; and let BC, another side, be in any convenient direction; fasten two ends of two of those lines at C and A; then the other ends (at D) being kept together, and the lines stretched on the ground, those lines AD, CD, will form the other two sides of the rhombus. Set up a mark at R, where OC, AD, intersect; and measure RD; then the sides of the triangles RDC, CBO, being respectively parallel, the triangles will be similar hence

Fig. 111.



RD: DC: :CB: BO.

Suppose the side of the rhombus is 100 feet, and RD=11 feet, 7 inches—then, $11\frac{7}{12}$: 100: :100: 863 *feet nearly*=BO.

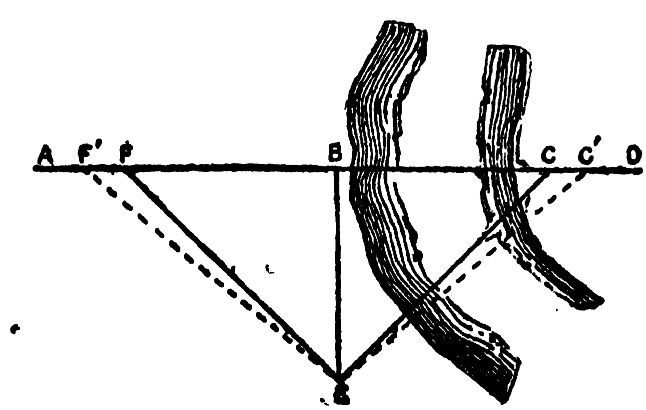
If the ground be nearly level, a rhombus, whose side is 100 feet, will determine distances to the extent of 300 yards within a very few feet of the truth. The principal involved in the above is best understood by imagining a tape of 100 feet stretched around ABCD so that the figures for 0, 25, 50, 75 and 100 feet touch pegs at ABCDA; any multiple of the above may be taken to suit the case.

243. *To find the length of the line* AD, *inaccessible at the point* D.

The measurement of the line AD, supposed to be run for the determination of a boundary, is stopped at B by a river or other obstacle.

The point F is taken up in the line at about the estimated breadth of the obstacle from B; and a mark set up at E at right angles to AD from the point B, and about the same distance as BF. The theodolite being adjusted at E, the angle BEO is made equal to BEF, and a mark put up at O in the line AD; BO is then evidently equal to the measured distance FB.

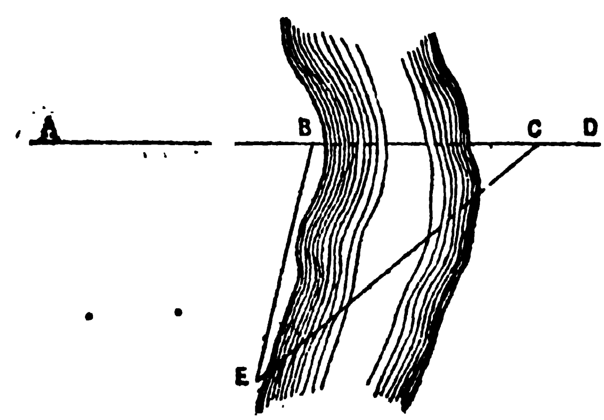
Fig. 112.



If the required termination of the line should be at any point C′, its distance from B can be determined by merely reversing the order of the operation, and making the angle BEF′ equal to BEC′, the distance BF′ being subsequently measured. There is no occasion in either case to *read* the angles. The instrument being levelled and clamped at zero, or any other marked division of the limb, is set on B: the *upper plate* is then unclamped and the telescope pointed at I, when being again clamped, it is a second time made to bisect B; releasing the plate, the telescope is moved towards D till the vernier indicates zero, or to whatever number of degrees it was first adjusted, and the mark at C has then only to be placed in the line AD, and bisected by the intersection of the cross wires of the telescope.

If it is impossible to measure a right angle at B from some local obstruction, lay off any convenient angle ABE and set up the theodolite at E. Make the angle BEC equal to *one-half* of ABE, and a mark being set up at C in the prolongation of AB, BC is evidently equal to BE, which must be measured, and which may at the same time be made subservient to the purpose of delineating the boundary of the river.

Fig. 113.



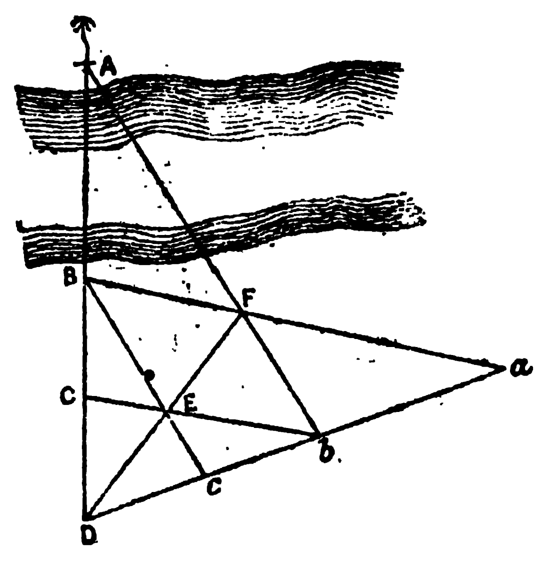
The reasoning of this is very simple; the angle ABE=the two angles BEC and BCE; but BEC is half ABE, consequently BCE is half ABE; therefore BEC=BCE, and therefore BC=BE.

244. *To find the distance to any inaccessible point, on the other side of a river, without the use of any instrument to measure angles.*

Prolong AB to any point D; making BC equal to CD; lay off the same distances in any direction D*c*—*cb*: mark the intersection E of the lines joining B*c*: and C*b* mark also F the intersection of DE produced and of A*b*—produce D*b* and BF, till they meet in *a*, and

$$\left.\begin{array}{l} ab = AB \\ ac = AC \\ aD = AD \end{array}\right\}$$

Fig. 114.

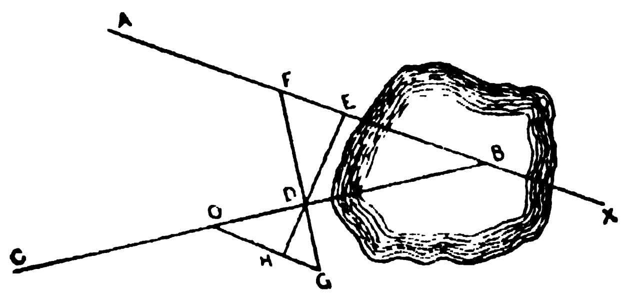


From the similarity of the figure the reasoning is self-evident.

245. *To find the point of intersection of two lines meeting in a lake or river and the distance* DB *to the point of meeting.*

From any point F on the line AX draw FD, and from any other point E draw ED, produce both these to H and G, making the prolongations either equal to the lines themselves, or any aliquot part of either length, suppose one-half; join GH, and produce it to O, where it meets the line CB, then OH is one-half of EB, and OD equal to half of DB; which results give the point of intersection B, and the distance to it from D.

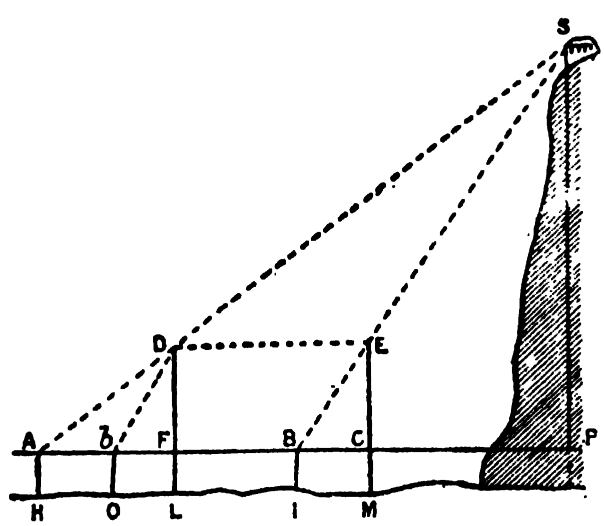
Fig. 115.



246. *To find the height of a point on an inaccessible hill without the use of instruments.*

Drive a picket three or four feet long at H, and another at L, where the top of a long rod FD is in a line with the object S from the point A (the heads of these pickets being on the same level); mark also the point C where the head of the rod is in the same line with S, from the top of any other picket B, and measure AF and BC; lay off the distance BC from F to *b*. and the two triangles AD*b* and ASB, are evidently similar, whence,

Fig. 116.



$$\frac{PS}{DF} = \frac{AS}{AD} = \frac{AB}{Ab} = \frac{HI}{HO} \text{ and } \frac{AP}{AF} \quad \frac{AS}{AD} = \frac{AB}{Ab} = \frac{HI}{HO}$$

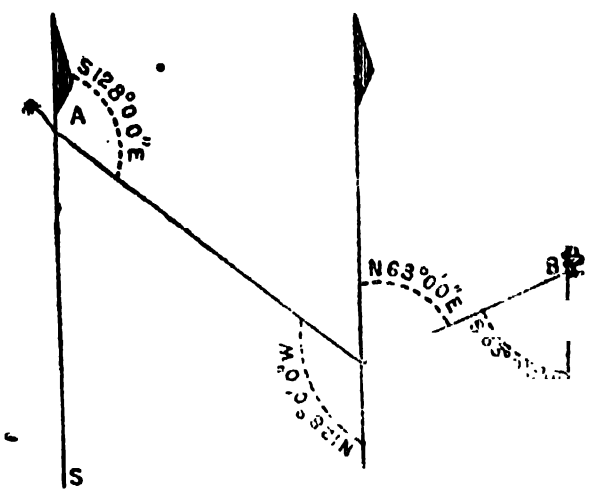
therefore $PS = \frac{DF \cdot HI}{HO}$ and $AP = \frac{AF \cdot HI}{HO}$.

247. *To find your place in a Survey.*

Let A and B be two stations, whose places are fixed, and *c*, the point to be determined. A very little thought will convince the student that the two bearings of any line as read at both ends must bear

some fixed relation to each other; such relation being a constant difference of two right angles. Take the bearing of A, 128° N.W.; consequently C bears from A, 128° S.E. Adjust the protractor at A, by means of the east and west parallel lines, and lay off 128° S.E. the bearing of C; which

Fig. 117.



point C must lie somewhere in the line thus obtained. Next, take the bearing of B 63° N. E. and having adjusted the protractor at B, lay off 63° S.W., and where a line drawn from B (to represent this bearing) cuts the line or bearing drawn from A, is the required station C.

The above may be put into a short rule, thus—*To find a station by observations taken to two points already known.* Protract *from* those points the *opposite* bearings to those observed; their intersection fixes the place sought. For example, if the bearing to a point be 20°, protract from that point 200° (= 180 + 20), &c.

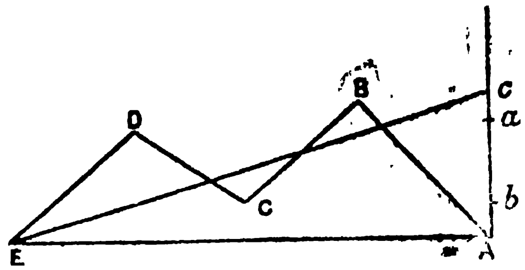
Note.—That the nearer the two bearings meet at a right angle, the more correct will the station be determined; and also, that when a third fixed point can be seen, a bearing to it will serve to corroborate the other observations; and a point so obtained, namely, by the exact meeting of three bearings, becomes as well defined as any other point.

The above is a very useful problem; and indispensable when sketching ground and filling in a survey.

248. *To reduce the off-set piece* ABCDE *to a right-angled triangle* AE*c, of the same area, by an equalizing line* E*c, with the parallel ruler.*

Draw the indefinite line A*c* perpendicular to AE. Lay the parallel ruler from A to C: hold the near side of the ruler firmly, and move the further side to B, which will cut A*c* at *a*, where a mark must be made. Lay the ruler from *a* to D, and the further side thereof being now held

Fig. 118.



fast, bring the near side to C, making Ac at b. Lay the ruler from b to E, move it parallel to D, marking Ac at c. Join Ec; then AEc is the right-angled triangle required, and its area may be found by taking half the product of AE and Ac.

The reasoning for the above various steps will be at once seen on reference to page 39, where the method of reducing a polygon to a triangle is described.

The following is a General Rule for solving Problems of this kind.

249. Draw a temporary line, as Ac, at right angles, or at any other angle to the chain line, as AE, of the off-sets.

1. Lay the ruler from the first to the third angle, and move it parallel to the second angle; then make the first mark on the temporary line.

2. Lay the ruler from the first mark on the temporary line to the fourth angle, and move it parallel to the third angle; then make the second mark on the temporary line.

3. Lay the ruler from the last-named mark to the fifth angle, and move it parallel to the fourth angle, then make the third mark on the temporary line.

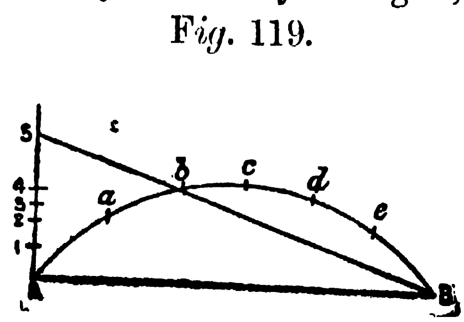
4. Lay the ruler from the last-named third mark on the temporary line to the sixth angle, and move it parallel to the fifth angle; then make the fourth mark on the temporary line.

In this manner the work of casting by the parallel ruler may be conducted to any number of angles. Great care must be taken during the operation to prevent the ruler slipping, as such an accident will derange the whole of the work, if not discovered and immediately corrected.

250. *To reduce a curved off-set piece to a right-angle triangle of the same area.*

Let A$abcde$B be the curved off-set piece. Divide the curve by points a, b, &c., so that the parts Aa, ab, &c., may be nearly straight; and draw A5 perpendicular to AB. Lay the ruler from A to b; move it parallel to a, and mark A5 at 1. Lay the ruler from 1 to c; move it parallel to b, and mark A5 at 2. Lay the ruler from 2 to d; move it parallel to c and mark A5 at 3. Lay the ruler from 3

Fig. 119.

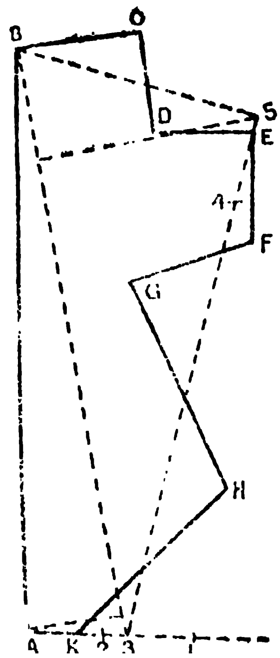


to *e*; move it parallel to *d*, and mark A5 at 4. Lay the ruler from 4 to B; move it parallel to *e*, and mark A5 at 5. Draw the line B5; then will AB5 be a right-angled triangle equal in area to the off-set piece A*abcde*B, as required.

251. *To reduce the irregular field* ABCDEFGHK *to a trapezium of the same area.*

Prolong the line AK at pleasure. Lay the ruler from K to G: move it parallel to H, and mark AK prolonged at 1. Lay the ruler from 1 to F: move it parallel to G, and mark AK at 2. Lay the ruler from 2 to E: move it parallel to F, and mark A 1 at 3. Draw a line 3 to E and prolong from E. Lay the ruler from E to C; move it parallel to D, and mark 3E at 4. Lay the ruler from 4 to B; move it parallel to C and mark 1E prolonged at 5. Draw a line from 5 to B; then shall AB53 be a trapezium, equal in area to the irregular figure ABCDEFGHK; the area of which may be found by multiplying the diagonal B3 by half the sum of the perpendiculars thereon from A and 5.*

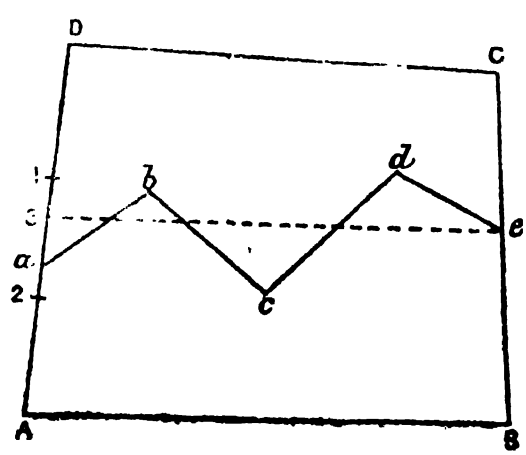
Fig. 120.



252. *To draw an equalizing line through the crooked fence, abcde, so that the two fields* AB*ea*, *a* DC*e*, *may be four-sided.*

Lay the ruler from *a* to *c*; move it parallel to *b*, and mark AD at 1. Lay the ruler from 1 to *d*; move it parallel to *c*, and mark AD at 2. Lay the ruler from 2 to *e*; move it parallel to *d*; and mark AD at 3. Draw the line *e*, and it will divide the two fields so that their quantities shall be the same as those before separated by the crooked fence *abcde*.

Fig. 121.



* NOTE. In this manner the crooked sides of a field may be successively reduced to straight ones. Thus if the side AB had been crooked, the operation of straightening might be continued by prolonging the dotted line 5B, and find successive points therein, corresponding to the assumed angles, till the last angle was brought thereon, and so on with respect to the side AK, had it also been crooked. When the sides of a field are curved, the method of reducing them to straight lines is the same as shown in Problem XIV.

It is scarcely necessary to add, that had the fence *abcde* been curved the equalizing line might have been found as in Problem XIV.

253. *To trace on the ground with a chain, a triangle, whose three sides are given.*

First.—When the sides are under 100 feet in length.

Lay off the longest sides first, mark its two ends by pickets; then from one end as centre, and the length of either of the other sides as radius, trace an arc upon the ground. With the other end of the fixed line as centre, and the length of the third side as radius, describe a second arc cutting the first arc, the triangle formed by joining the intersection of these arcs with the ends of the base is the one required.

Second.—When the sides are longer than the chain.

In this case a small triangle with its sides less than the length of the chain, but proportionll to the given sides, must be first laid down as in the first case, then two of the sides must be produced to their proper lengths, and the line joining their ends will be the third side required.

For instance, suppose a triangle whose sides are 456, 384 and 296 feet, respectively, has to be traced.

Take ¼th part of each of the sides, this gives 114, 96 and 74 feet. Then lay down a line 114 feet long, from one end sweep an arc of 96 feet radius, and from the other end an arc of 74 feet radius; mark their intersection. Then produce the 114 feet side, and the 96 feet side to their required lengths, *i.e.* till they are 456 and 384 feet, respectively; then the line joining their ends will be the third side required, and will be 296 feet long.

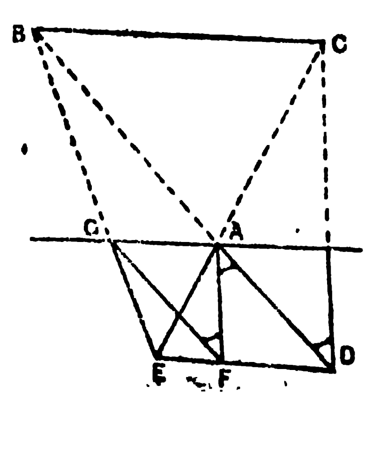
254. *Through a given point to trace a line parallel to a given line.*

First.—When the given line is accessible.

From the given point A draw any convenient line AB to meet the given line BC. Find the magnitude of the angle ABC, these two lines make with each other; at the given point A, lay off an alternate angle BAG of equal magnitude, this will at once give the required parallel line AG.

Second.—When the given line is inaccessible.

Fig. 122.



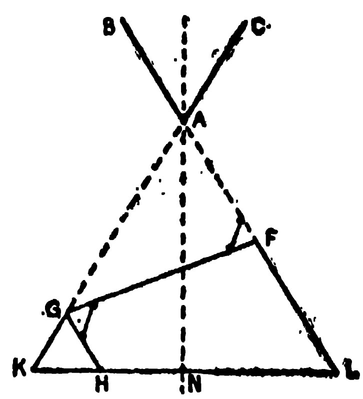
BC is the inaccessible line, and A is the given point. Take any points, D and E, in the continuations of the lines BA and CA. Find the magnitude of the angle CDA, draw AF parallel to CD, find F in the line DE. Through F draw FG parallel to DA, and find G in the line EB: then the line through G and A is parallel* to AB.

This problem is of great use to the military engineer. If BC is the face of a bastion, GA would be the direction of the crest line of a battery to fire directly against BC; and by knowing the length of BC the number of guns to be silenced is also known.

*255. *To find the prolongation of the capital of a bastion or ravelin.*

Take any points F and G in the prolongations of the faces, join GF, draw GH parallel to AF. Take GK any convenient distance, and make GH equal to it, join K and H, and produce the line KH to N. Bisect KL in N, then the point N is in the prolongation of the line bisecting the angle BAC.

Fig. 123.



This problem is of great use in tracing the parallels of attack in a siege.

* The proof is very simple:—In the similar triangles DEB, EFG,

$$EG : EB = EF : ED.$$

But in the similar triangles EFA, EDC, $EF : ED = EA : EC$.

Therefore $EG : EB = EA : EC$. And therefore GA is parallel to BC.

BC may also be determined in length without further construction.

Because $EF : ED = EA : EC = GA : BC$.

Therefore $BC = \dfrac{GA \times ED}{EF}$

256. *To find heights and distances by the aid of the pocket sextant.*

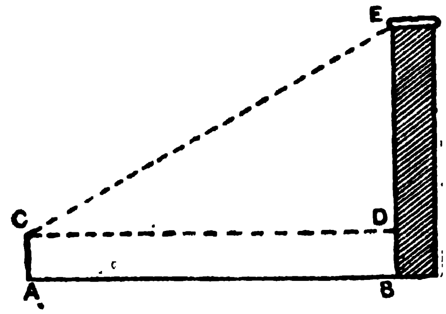
The height and distance of objects, as walls or buildings, whether accessible or otherwise, may be obtained in a very simple and expeditious manner with the sextant, by means of the following table:—

Multiplier.	Angle.	Angle.	Divisor.
1	45°00′	45°00′	1
2	63 26	26 34	2
3	71 34	18 26	3
4	75 58	14 02	4
5	78 41	11 19	5
6	80 32	9 28	6
8	82 52	7 08	8
10	84 17	5 43	10

Make a mark upon the object, if accessible, equal to the height of your eye from the ground. Set the index to one of the angles in the table, and advance or retire along level ground, until the top is brought by the glasses to coincide with the mark; then, if the angle be greater than 45° multiply the distance by the corresponding figure to the angle in the table; if it be less, divide—and the product, or quotient, will be the height of the object above the mark.

Thus, let EB be a wall, whose height is required; and 26° 34′ the angle selected. Make a mark at D equal to the height of the eye; then step back from the wall. until the top at E is brought down by the glasses to coincide with the mark; measure the distance AB, and divide that distance by 2, the figure corresponding to 26° 34′, this will give the height DE, to which BD must be added.

Fig. 124.



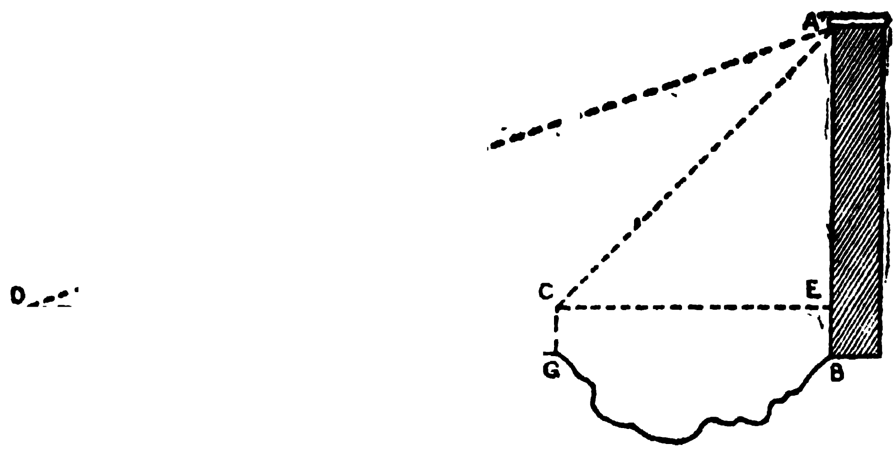
The *parallax* of the instrument exerts an influence on measurements of this kind, from the object being near. This should first be noted, and if appreciable must be allowed for, care being taken that when the amount of parallax is read on the arc of excess, the amount must be deducted, when setting the instrument to any of the tabular angles. If the allowance for parallax is read on the arc of excess it must be added to the angles (see para. 89).

When the object is inaccessible—set the index to the greatest of the divisor angles in the table, that the least distance from the object will admit of, and advance or recede, till the top of it be brought down by the sextant to a level with the eye; at this place, set up a staff, equal to the height of the eye. Then set the index to one of the lesser angles, and retire in a line from the object, till the top be brought to coincide with the staff, set up to indicate the height of the eye; place a mark here, and measure the distance between the two marks; this, divided by the difference of the figure opposite the angles used, will give the height of the object above the height of the eye or mark. *For the distance*, multiply the height of the object by the numbers against either of the angles made use of, and the product will be the distance of the object from the place where such angles were used.

The above will be understood better by means of a diagram. Let AB be a wall, not to be approached nearer than C; and that it is found upon trial, that this distance admits of the angle 45° being used assume a point E on the wall, as the height of the eye; then the index being set to 45°, the observer must station himself so that the glass shall bring the top A to coincide with E. At this point, place a staff, CG, equal to the height of the eye. Now having selected at any one of the lesser angles from the tables—18° 26′, for instance, retire until the point A agrees with the top of the staff CG, which occurs at F. Place a mark at F and measure

the distance from F to G; which, divided by 2 (the difference of the numbers

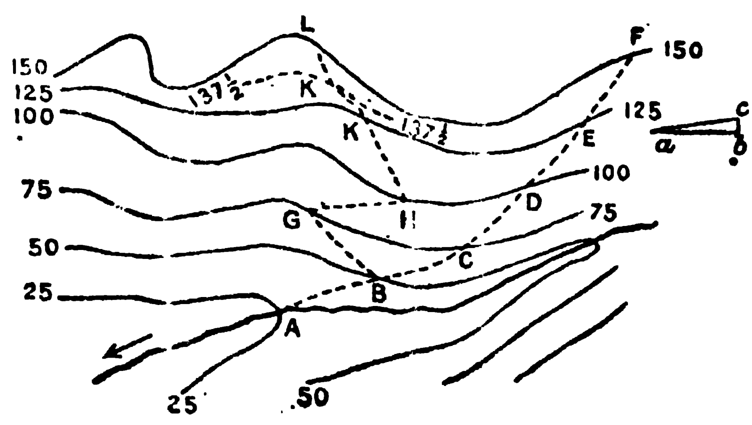
Fig. 125.



opposite to the angles used), will give AE—to which add BE = CG, the height of the eye, and the total height AB is obtained. Then, for the distance,—the height AE, multiplied by 3, its corresponding figure, will give the length DE; and AE multiplied by 1, will, in a like manner, give GB = AE in this instance.

257. *To lay out the direction of a road on a hill-side at any given slope.*

Fig. 126.



Scale—8 *inches to* 1 *mile.*

Let the figure represent the contoured plan of a hill-side along which it is required to lay out the direction of a road, rising from the point A to the level 150 at a uniform gradient of 1 in 8. As the interval between the contours is 25 feet, the plan of the road between any two contours will be the base of a right-angled triangled abc, in which $ab = 25 \times 8 = 200$ feet. Laying of this distance on the same scale as the map (8 inches to 1 mile) between the successive contours at BCD, &c., the required direction is determined. Should a zigzag not be objectionable, the road may be made to follow the course BGHKL.

It sometimes happens that the course of the road between two contours close together is not quite clear. In this case an intermediate contour must be interpolated, as 137½ in the figure, and the KK′ = 100 feet laid off between 125 and 137½, and a further length K′L of 100 feet between 137½ and 150.

As an exercise the student is recommended to the following example :—

Draw four concentric circles, ½-inch apart: diameter of the smallest circle ·75 inch. Assuming these circles to be the contours (50 feet interval) of a conical hill, draw the track of a road ascending from the lowest contour to the summit, at a slope of 1 in 20. Scale--6 inches to 1 mile.

258. *To find the boundary of excavation or filling on a contoured plan.*

In a problem of this nature, see fig. 127, it is necessary to assume that A and B are more or less ruling points or that A and B by trial have been found to give a better gradient, and avoid expensive bridging, protection of permanent way, &c.

To find the boundary of excavation it is necessary first therefore to lay down on the survey the road alignment with the adopted width of road-bed and to show thereon the probable gradient. Next at right angles to the alignment the plan of the contours representing the slope of embanking or cutting—in this case 1½ to 1. The points on the map where these contours intersect the contours of the surveyed map furnish the cutting edge of excavation and the filling edge required. Quantities can be worked out from the above with sufficient accuracy for a preliminary estimate.

TABLE I—Curve Tables.

TABLE OF NATURAL TANGENTS & SINES.			TABLE OF CHORDS AND OFF-SETS.									
NATURAL TANGENTS AND SINES.			100 FEET CHORDS.						LONG CHORDS TO SAME RADIUS			
Angle.	Natural tangent and difference for 1 minute.	Natural sine and difference for 1 minute.	Central angle of chord of 100 feet $= a =$ ACB.	Radius $= 50 \operatorname{cosec} \frac{a}{2} =$ AC.	Deflection distance $= 200 \sin \frac{a}{2} =$ ED = 2TB.	Arc of 1' $= \frac{2\pi r}{360} = \frac{100\pi}{360} . \operatorname{cosec} \frac{a}{2} = 0·8727 \operatorname{cosec} \frac{a}{2}$	Off-set at 25 feet on 100 feet chord $= 25 \tan \frac{3a}{8}$ very nearly = LM = No.	Off-set at centre of 100 feet chord $= 50 \tan \frac{a}{4} =$ PQ.	Chord subtending four chords of 100 feet or $4a = 2r \sin 2a = 100 \operatorname{cosec} \frac{a}{2} \sin 2a =$ AG.	Abscissa of 1st 100 foot chord on above $= 100 \cos \frac{3a}{2} =$ AH = GI.	Off-set from last point to end of first chord of 100 $= 100 \sin \frac{3a}{2} =$ HB = IF.	Central off-set on chord of $4a = 100 \sin \frac{3a}{2} + 100 \sin \frac{a}{2} =$ KD.
°			° '									
0	·000000	000000	0 2	171887·34	0·06	3000·007	0·00	0·01	400·00	100·00	0·09	0·12
	000291	000291	4	85943·67	0·12	1500·003	0·01	0.02	,,	,,	0·17	0·23
1	·017455	017452	6	57295·79	0·17	1000·002	0·02	0·03	399·99	,,	0·26	0·35
	000291	000291	8	42971·84	0·23	750·002	0·02	0·03	,,	,,	0·35	0·47
2	·034921	034899	10	34377·48	0·29	600·001	0·03	0·04	,,	,,	0·44	0·59
	000291	000291	12	28647·91	0·35	500·001	0·03	0·04	,,	,,	0·52	0·69
3	·052408	052336	14	24550·35	0·41	428·572	0·04	0·05	,,	,,	0·61	0·81
	000292	000290	16	21845·39	0·47	375·001	0·04	0·06	,,	,,	0·70	0·93
4	·069927	069756	18	19098·62	0·52	333·333	0·04	0·06	,,	,,	0·79	1·05
	000293	000290	20	17188·76	0·58	300·001	0·05	0·07	,,	,,	0·87	1·16
5	·087489	087156	22	15626.15	0·64	272·727	0·06	0·08	,,	,,	0·99	1·31
	000294	000289	24	14323·97	0·70	250.001	0·07	0·09	,,	99·99	1·05	1·40
6	·105104	104528	26	13222·13	0·76	230·770	0·07	0·09	,,	,,	1·13	1·51
	000295	000289	28	12277·75	0·81	214·237	0·07	0·10	399·98	,,	1·22	1·63
7	·122785	121869	30	11459·19	0·87	199·541	0·08	0·11	,,	,,	1·31	1·75
	000296	000288	32	10743·00	0·93	187·501	0·09	0·12	,,	,,	1·40	1·87
8	·140541	139173	34	10111·06	0·99	176·471	0·09	0·12	,,	,,	1·48	1·97
	000297	000288	36	9549·34	1·05	166·667	0·10	0·13	399·97	,,	1·57	2·09
9	·158384	156434	38	9046·75	1·11	157·859	0·10	0·14	,,	,,	1·66	2·21
	000299	000287	40	8594·41	1·16	150·001	0·11	0·15	,,	99·98	1·75	2·33
10	·176327	173648	42	8185·16	1·22	142·858	0·11	0·15	399·96	,,	1·83	2·44
	000301	000286	44	7813·11	1·28	136·280	0·12	0·16	,,	,,	1·92	2·56
11	·194380	190809	46	7473·42	1·34	130·436	0·12	0·16	,,	,,	2·01	2·68
	000303	000285	48	7162·03	1·40	125·001	0·13	0·17	399·95	,,	2·09	2·79
12	·212557	207912	50	6875·55	1·45	120·001	0·13	0·18	,,	,,	2·18	2·91
	000305	000284	52	6611·11	1·51	115·386	0·14	0·19	399·94	99·97	2·27	3·03
13	·230868	224951	54	6366·26	1·57	111·112	0·14	0·19	,,	,,	2·36	3·15
	000308	000283	56	6138·90	1·63	107·144	0·15	0·20	,,	,,	2·44	3·25
14	·249328	241922	58	5927·22	1·69	103·450	0·15	0·21	,,	,,	2·53	3·37
	000310	000282	1 0	5729·65	1·75	100·001	0·16	0·22	399·92	,,	2·62	3·49
15	·267949	258819	4	5371·56	1·86	93·752	0·17	0·23	·91	,,	2·79	3·72
	000313	000280	8	5055·59	1·98	88·237	0·19	0·24	·90	,,	2·97	3·95
16	·286745	275637	12	4774·73	2·09	83·335	0·20	0·26	·89	99·95	3·14	4·19
	000316	000279	16	4523·44	2·21	78·949	0·21	0·28	·88	,,	3·32	4·43
17	·305731	292372	20	4297·28	2·33	75·002	0·22	0·29	·86	99·94	3·49	4·65
	000320	000278	24	4092·65	2·44	71·430	0·23	0·31	·85	·93	3·66	4·88
18	·324920	309017	28	3906·64	2·56	68·184	0·24	0·32	·83	·93	3·84	5·12
	000323	000276	32	3736·79	2·68	65·219	0·25	0·33	·82	·92	4·01	5·35
19	·344328	325568	36	3581·10	2·79	62·502	0·26	0·35	·81	·91	4·19	5·59
	000327	000274	40	3437·87	2·91	60·002	0·27	0·36	·79	·90	4·36	5·81
20	·363970	342020	44	3305·65	3·03	57·695	0·28	0·37	·77	·90	4·54	6·05
	000332	000272	48	3183·33	3·14	55·558	0·29	0·39	·75	·89	4·71	6·28
21	·383864	358368	52	3069·50	3·26	53·574	0·30	0·41	.73	·88	4·89	6·52
	000336	000271	56	2963·72	3·37	51·727	0·31	0·43	·71	·87	5·06	6·75
22	·404026	374607	2 0	2864·93	3·49	49·970	0·32	0·44	·70	·86	5·23	6·98
	000341	000269	6	2728·52	3·67	47·622	0·34	0·46	.67	·85	5·50	7·38

TABLE I.—Curve Tables—(*concluded*).

Angle.	Nat. tan.	Nat. sine.	ACB.	AC.	2TB or ED.	Arc of 1°.	LM.	PQ.	AG.	AH.	HB.	KD.
°			° ′									
23	·424475	390731	2 12	2604·51	3·84	45·458	0·36	0·48	399·63	99·83	5·76	7·68
	000346	000267	18	2491·29	4·01	43·481	0·38	0·50	·59	·82	6·02	8·03
24	·445229	406737	24	2387·50	4·19	41·680	0·40	0·52	·56	·80	6·28	8·37
	000351	000265	30	2292·01	4·36	40·016	0·42	0·55	·52	·79	6·54	8·72
25	·466308	422618	36	2203·77	4·54	38·465	0·44	0·57	·49	·77	6·80	9·07
	000357	000262	42	2122·26	4·71	37·040	0·45	0·57	·44	·75	7·06	9·42
26	·487733	438371	48	2046·48	4·89	35·717	0·46	0·61	·40	·73	7·32	9·76
	000363	000260	54	1975·93	5·06	34·487	0·48	0·63	·36	·71	7·58	10·11
27	·509525	453990	3 0	1910·08	5·23	33·337	0·50	0·65	·32	·69	7·85	10·47
	000370	000258	6	1848·48	5·41	32·262	0·51	0·67	·27	·67	8·11	10·81
28	·531709	469472	12	1790·73	5·58	31·254	0·52	0·70	·22	·65	8·37	11·16
	000376	000256	18	1736·48	5·76	30·306	0·54	0·72	·17	·63	8·63	11·51
29	·554309	484810	24	1685·42	5·93	29·416	0·56	0·74	·12	·60	8·89	11·86
	000384	000253	30	1637·28	6·11	28·576	0·58	0·76	·07	·58	9·15	12·20
30	·577350	500000	36	1591·81	6·28	27·782	0·59	0·79	·01	·56	9·41	12·55
	000392	000251	42	1548·80	6·46	27·032	0·61	0·81	398·96	·53	9·67	12·90
31	·600860	515038	48	1508·06	6·63	26·321	0·63	0·83	·90	·51	9·93	13·24
	000400	000248	54	1469·41	6·81	25·646	0·64	0·85	·84	·48	10·19	13·59
32	·624869	529919	4 0	1432·69	6·98	25·005	0·65	0·87	·78	·45	10·45	13·94
	000409	000245	12	1364·49	7·33	23·815	0·69	0·92	·66	·40	10·97	14·63
33	·649407	544639	24	1302·50	7·68	22·733	0·72	0·96	·53	·34	11·49	15·33
	000418	000243	36	1245·90	8·03	21·745	0·75	1·00	·39	·28	12·01	16·02
34	·674509	559193	48	1194·01	8·38	20·835	0·79	1·05	·25	·21	12·53	16·72
	000428	000240	5 0	1146·28	8·72	20·006	0·82	1·09	·10	·14	13·05	17·41
35	·700208	573576	12	1102·22	9·07	19·237	0·85	1·13	397·94	·07	13·57	18·11
	000439	000237	24	1061·43	9·42	18·525	0·88	1·18	·78	·00	14·09	18·86
36	·726543	587785	36	1023·55	9·77	17·864	0·92	1·22	·62	98·93	14·61	19·50
	000450	000235	48	988·28	10·12	17·249	0·95	1·27	·44	·85	15·13	20·19
37	·753554	601815	6 0	955·37	10·47	16·674	0·98	1·31	·26	·77	15·64	20·57
	000462	000231	12	924·58	10·82	16·137	1·01	1·35	·08	·69	16·16	21·57
38	·781286	615661	24	895·71	11·16	15·633	1·05	1·40	·89	·60	16·68	22·26
	000475	000226	36	868·60	11·51	15·160	1·08	1·44	396·69	·51	17·19	22·95
39	·809784	629320	48	843·08	11·86	14·715	1·11	1·48	·49	·42	17·70	23·63
	000489	000224	7 0	819·02	12·21	14·295	1·14	1·53	·28	·32	18·22	24·32
40	·839100	642788	12	796·30	12·56	13·899	1·18	1·57	·06	·23	18·74	25·02
	000503	000221	24	774·81	12·91	13·523	1·21	1·62	395·84	·13	19·25	25·70
41	·869287	656059	36	754·44	13·25	13·167	1·24	1·67	·61	·03	19·77	26·40
	000519	000218	48	735·13	13·60	12·830	1·27	1·70	·39	97·92	20·28	27·08
42	·900404	669131	8 0	716·78	13·95	12·510	1·31	1·75	·14	·81	20·79	27·77
	000536	000214	12	699·33	14·30	12·205	1·34	1·78	394·99	·70	21·30	28·45
43	·932515	681998	24	682·70	14·65	11·915	1·38	1·83	·65	·59	21·81	29·13
	000553	000211	36	666·86	15·00	11·639	1·41	1·88	·39	·48	22·32	29·82
44	·965689	694658	48	651·73	15·34	11·375	1·44	1·92	·13	·36	22·84	30·51
	000572	000208	9 0	637·27	15·69	11·123	1·47	1·96	393·86	·24	23·34	31·19
45	1·000000	707107	20	614·56	16·27	10·726	1·53	2·04	·40	·03	24·19	32·33
	000592	000204	40	593·42	16·85	10·357	1·59	2·11	392·92	96·81	25·04	33·47
46	1·035530	719340	10 0	573·64	17·43	10·013	1·64	2·18	·43	·59	25·88	34·60
	000614	000200	30	546·44	18·30	9·537	1·72	2·29	391·65	·25	27·14	36·29
47	1·072369	731354	11 0	521·67	19·17	9·105	1·80	2·40	390·84	95·88	28·40	37·98
	000637	000197	30	499·06	20·04	8·710	1·89	2·52	·00	·50	29·65	39·67
48	1·110613	743145	12 0	478·34	20·91	8·349	1·97	2·62	389·12	·11	30·90	41·35
	000663	000193	30	459·28	21·77	8·016	2·05	2·72	388·20	94·69	32·14	43·03
49	1·150368	754710	13 0	441·68	22·64	7·762	2·12	2·84	387·24	·26	33·38	44·70
	000690	000189	30	425·40	23·51	7·425	2·21	2·94	386·25	93·81	34·61	46·36
50	1·191754	766044	14 0	410·28	24·37	7·161	2·30	3·06	385·23	·36	35·84	48·03
	000712	000185	30	396·20	25·24	6·915	2·38	3·17	384·16	92·88	37·06	49·68
51	1·234490	777146	15 0	383·06	26·11	6·881	2·47	3·28	383·07	·39	38·27	51·32
	000756	000181	16 0	359·26	27·83	6·270	2·63	3·50	380·76	91·36	40·67	54·59
52	1·279942	788011	17 0	338·27	29·56	5·904	2·79	3·72	378·32	90·26	43·05	57·83
	000785	000177	18 0	319·62	31·29	5·578	2·96	3·94	375·74	89·10	45·40	61·04
53	1·327045	798636	19 0	302·94	33·01	5·287	3·15	4·15	373·02	87·88	47·72	64·22
	000822	000178	20 0	287·94	34·78	5·025	3·29	4·37	370·16	86·60	50·00	67·86

TABLE II.—Curves. Radius—5,000 feet.

	°	′	″
Angle subtending 1,000 feet chords	11	28	42
,, between 1,000 feet chords	168	31	18
,, between tangent and 1,000 feet chords ..	174	15	39

OFF-SETS FROM TANGENTS OF 1,000 FEET LENGTH.

Distance from poin of contact	Off-set.	Distance from point of contact.	Off-set.	Distance from point of contact.	Off-set	Distance from point of contact.	Off-set.
100	1·00	75	0·56	50	0 25	25	0·06
200	4·00	175	3 06	150	2·25	125	1·56
300	9·01	275	7·56	250	6·25	225	5·06
400	16·02	375	14·08	350	12·26	325	10·57
500	25·06	475	22·61	450	20·29	425	18·09
600	36·13	575	33·17	550	30·34	525	27·64
700	49·24	675	45·77	650	42·43	625	39·22
800	64·41	775	60·44	750	56·57	725	52·84
900	81·67	875	77·16	850	72·78	825	68·53
1,000	101·02	975	95·98	950	91·08	925	86·04

OFF-SETS FROM CHORDS.

Length of chord.	Off-sets from— Centre.	100.	200.	300.	400.	Length of chord.	Off-sets from— Centre.	100.	200.	300.	400.
1,000	25·06	24·06	21·06	16·05	9·04	950	22·61	21 61	18·61	13·60	6·59
900	20·28	19·28	16·28	11·27	4·25	850	18·09	17·09	14·09	9·08	2·07
800	16·02	15·02	12·02	7·02		750	14·08	13·08	10·08	5·07	
700	12·26	11·26	8·26	3·25		650	10·57	9·57	6·57	1·56	
600	9·01	8·00	5·00			550	7·57	6·56	3·56		
500	6 25	5·25	2·25			450	5·06	4·06	1·06		
400	4·00	3·00				350	3·06	2·06			
300	2·25	1·25				250	1·56	0·56			
200	1·00					150	0·56				
100	0·25					50	0·06				

TABLE III.—Curves. Radius=10,000 feet.

Angle subtending 1,000 feet chords	5	43	54
„ between 1,000 feet chords	174	16	6
„ between tangent and 1,000 feet chords	177	8	3

OFF-SETS FROM TANGENTS.

Distance from point of contact.	Off-set.	Distance from point of contact.	Off-set.	Distance from point of contact.	Off-set.	Distance from point of contact.	Off-set.
100	0·50	75	0·28	50	0·12	25	0·03
200	2·00	175	1·53	150	1·12	125	0·78
300	4·50	275	3·78	250	3·12	225	2·53
400	8·00	375	7·03	350	6·13	325	5·28
500	12·51	475	11·28	450	10·13	425	9·03
600	18·02	575	16·55	550	15·14	525	13·79
700	24·53	675	22·81	650	21·15	625	19·55
800	32·05	775	30·08	750	28·16	725	26·31
900	40·58	875	38·36	850	36·19	825	34·08
1,000	50·13	975	47·65	950	45·23	925	42·87

OFF-SETS FROM CHORDS.

Length of chord.	Off-sets from— Centre.	100.	200.	300.	400.	Length of chord.	Off-sets from— Centre.	100.	200.	300.	400.
1,000	12·51	12·01	10·50	8·00	4·50	950	11·28	10·78	9·28	6·78	3·28
900	10·13	9·63	8·13	5·63	2 13	850	9·03	8·53	7·03	4·53	1·03
800	8·00	7·50	6·00	3·50		750	7·03	6·53	5·03	2·53	
700	6·13	5·63	4·12	1·62		650	5·28	4·78	3·28	0·78	
600	4·50	4·00	2·50			550	3·78	3·28	1·78		
500	3·12	2·62	1·12			450	2·53	2·03	0·53		
400	2·00	1·50				350	1·53	1·03			
300	1·12	0·62				250	0·78	0·28			
200	0·50					150	0·28				
100	0·12					50	0·03				

TABLE IV.—Curves. Radius = 15,000 feet.

	°	′	″
Angle subtending 1,000 feet chords	7	38	40
„ between 1,000 feet chords	172	21	20
„ between tangent and 1,000 feet chords	176	10	40

OFF-SETS FROM TANGENTS.

Distance from point of contact.	Off-set.	Distance from point of contact.	Off-set.	Distance from point of contact.	Off-set.	Distance from point of contact.	Off-set.
100	0·33	75	0·19	50	0·08	25	0·02
200	1·33	175	1·02	150	0·75	125	0·52
300	3·00	275	2·52	250	2·08	225	1·69
400	5·33	375	4·67	350	4·08	325	3·52
500	8·33	475	7·52	450	6·75	425	6·02
600	12·01	575	10·02	550	10·09	525	9·19
700	16·34	675	15·19	650	14·09	625	13·03
800	21·35	775	20·03	750	18·76	725	17·53
900	27·02	875	25·54	850	24·10	825	22·70
1,000	33·37	975	31·72	950	30·11	925	28·55

	°	′	″
Angle subtending 2,000 feet chords	3	49	12
„ between 2,000 feet chords	176	10	48
„ between tangent and 2,000 feet chords	178	5	24

OFF-SETS FROM CHORDS.

Length of chord.	Off-sets from— Centre.	200.	400.	600.	800.	Length of chord.	Off-sets from— Centre.	200.	400.	600.	800.
500	2·08	·75				450	1·69	0·36			
600	3·00	1·67				550	2·52	1·19			
700	4·08	2·75				650	3·52	2·19			
800	5·33	4·00				750	4·67	3·34			
900	6·75	5·42	1·42			850	6·02	4·69	0·69		
1,000	8·33	7·00	3·00			950	7·52	6·19	2·19		
1,100	10·09	8·76	4·76			1,050	9·19	7·86	3·86		
1,200	12·00	10·67	6·67			1,150	11·02	9·69	5·69		
1,300	14·09	12·76	8·76	2·09		1,250	13·03	11·70	7·70	1·03	
1,400	16·34	15·01	11·01	4·34		1,350	15·19	13·86	9·86	3·19	
1,500	18·76	17·43	13·43	6·76		1,450	17·53	16·20	12·20	5·53	
1,600	21·35	20·02	16·02	9·35		1,550	20·03	18·70	14·70	8·03	
1,700	24·10	22·76	18·77	12·10	2·75	1,650	22·70	21·37	17·37	10·70	1·35
1,800	27·02	25·69	21·69	15·02	5·67	1,750	25·54	24·21	20·21	13·54	4·19
1,900	30·11	28·78	24·78	18·11	8·76	1,850	28·55	27·22	23·22	16·55	7·20
2,000	33·37	32·04	28·04	21·37	12·02	1,950	31·72	30·39	26·39	19·72	10·37

TABLE V.—Curves. Radius=20,000 feet.

Angle subtending 1,000 feet chords	2	51	54
„ between 1,000 feet chords	177	8	6
„ between tangent and 1,000 feet chords	178	34	3

OFF-SETS FROM TANGENTS.

Distance from point of contact.	Off-set.	Distance from point of contact.	Off-set.	Distance from point of contact.	Off-set.	Distance from point of contact.	Off-set.
100	0·25	75	0·14	50	0·06	25	0·01
200	1·00	175	0·76	150	0·56	125	0·39
300	2·25	275	1·89	250	1·56	225	1·26
400	4·00	375	3·51	350	3·06	325	2·64
500	6·25	475	5·64	450	5·06	425	4·52
600	9·00	575	8·27	550	7·56	525	6·89
700	12·25	675	11·39	650	10·57	625	9·77
800	16·00	775	15·02	750	14·07	725	13·14
900	20·26	875	19·15	850	18·07	825	17·02
1,000	25·01	975	23·78	950	22·57	925	21·40
1,100	30·27	1,075	28·91	1,050	27·58	1,025	26·28
1,200	36·03	1,175	34·54	1,150	33·09	1,125	31·66
1,300	41·29	1,275	40·68	1,250	39·10	1,225	37·55
1,400	49·06	1,375	47·32	1,350	45·61	1,325	43·94
1,500	56·32	1,475	54·46	1,450	52·63	1,425	50·83
1,600	64·10	1,575	62·11	1,550	60·15	1,525	58·22
1,700	72·38	1,675	70·26	1,650	68·18	1,625	66·12
1,800	81·12	1,775	78·92	1,750	76·71	1,725	74·53
1,900	90·45	1,875	88·09	1,850	85·75	1,825	83·44
2,000	100·25	1,975	97·75	1,950	95 29	1,925	92·86

Angle subtending 2,000 feet chords	5	43	52
„ between 2,000 feet chords	174	16	6
„ between tangent and 2,000 feet chords ..	177	8	3

OFF-SETS FROM CHORDS.

Length of chord.	Off-sets from—					Length of chord.	Off-sets from—				
	Centre.	200.	400.	600.	800.		Centre.	200.	400.	600.	800.
500	1·56	0·56				450	1·26	0·26			
600	2·25	1·25				550	1·89	0·89			
700	3·06	2·06				650	2·64	1·64			
800	4·00	3·00				750	3·51	2·51			
900	5·06	4·06	1·06			850	4·52	3·52	0·51		
1,000	6·25	5·25	2·25			950	5·64	4·64	1·64		
1,100	7·56	6·56	3 56			1,050	6·89	5·89	2·89		
1,200	9·00	8·00	5·00			1,150	8·27	7·27	4·27		
1,300	10·57	9·57	6·57	1·56		1,250	9·77	8·77	5·77	0·77	
1,400	12·25	11·25	8·25	3·25		1,350	11·39	10·39	7·39	2·39	
1,500	14·07	13·07	10·07	5·06		1,450	13·14	12·14	9·14	4·14	
1,600	16,00	15 00	12·00	7·00		1,550	15·02	14·02	11·02	6·02	
1,700	18·07	17·07	14·07	9·07	2·07	1,650	17·02	16·02	13·02	8·02	1·02
1,800	20·26	19·26	16·26	11·26	4·26	1,750	19·15	18·15	15·15	10·15	3·15
1,900	22·57	21·57	18 57	13·57	6·57	1,850	21·40	20·40	17·40	12·40	5·40
2,000	25·01	24·01	21·01	16·01	9·01	1,950	23·78	22·78	19·78	14·78	7·78

TABLE VI.—Curves. Radius = 25,000 feet.

Angle subtending 2,000 feet chords	4	34	5
„ between 2,000 feet chords	175	24	55
„ between tangent and chords	177	42	27

OFF-SETS FROM TANGENTS.

Distance from point of contact.	Off-set.	Distance from point of contact	Off-set.	Distance from point of contact.	Off-set.	Distance from point of contact	Off-set.
100	0·20		0·11	50	0·05	25	0·01
200	0·80	175	0·61	150	0·45	125	0·31
300	1·80	275	1·51	250	1·25	225	1·01
400	3·20	375	2·81	350	1·45	325	2·11
500	5·00	475	4·51	450	4·05	425	3·61
600	7·20	575	6·61	550	6·05	525	5·51
700	9·80	675	9·11	650	8 45	625	7·81
800	12·80	775	12·01	750	11·25	725	10·51
900	16·20	875	15·32	850	14·45	825	13·62
1,000	20·01	975	19·02	950	18·05	925	17·12
1,100	24 21	1,075	23·12	1,050	22·06	1,025	21·02
1,200	28·81	1,175	27·62	1,150	26·46	1,125	25·32
1,300	33·81	1,275	32·53	1,250	31·27	1,225	30·08
1,400	39·22	1,375	37·84	1,350	36·47	1,325	35·13
1,500	45·02	1,475	43·55	1,450	42·08	1,425	40·64
1,600	51·24	1,575	49·66	1,550	48·10	1,525	46·56
1,700	57·85	1,675	56·17	1,650	54·51	1,625	52 87
1,800	64·87	1,775	63·08	1,750	61·33	1,725	59·58
1,900	72·30	1,875	70·40	1,850	68·54	1,825	66·70
2,000	80 12	1,975	78·12	1,950	76·16	1,925	74·22

Angle subtending 1,000 feet chords	2	17	30
„ between 1,000 feet chords	177	42	30
„ between tangent and chords	178	51	15

OFF-SETS FROM CHORDS.

Length of chord.	Off-sets from— Centre.	200.	400	600.	800.	Length of chord.	Off-sets from— Centre.	200.	400	600.	800.
500	1·25	0·45				450	1·01	0·21			
600	1·80	1·00				550	1·51	0·71			
700	2·45	1·65				650	2·11	1·31			
800	3·20	2·40				750	2·81	2·01			
900	4·05	3 25	0·85			850	3·61	2·81	0·41		
1 000	5·00	4·20	1·80			950	4·51	3·71	1·32		
1,100	6·05	5·25	2·85			1,050	5·51	4·71	2·31		
1,200	7·20	6·40	4·00			1,150	6·61	5·81	3·41		
1,300	8·45	7·65	5·25	1·25		1,250	7·81	7·01	4·61	0·61	
1,400	9·80	9·00	6·60	2·60		1,350	9·11	8·31	5·91	1·91	
1,500	11·25	10·45	8·05	4·05		1,450	10·51	9·71	7·31	3·31	
1,600	12·80	12·00	9·60	5·60		1,550	12·01	11·21	8·81	4·81	
1,700	14·45	13·65	11·25	7·25	1·65	1,650	13·62	12·82	10·42	6·41	0·81
1,800	16·20	15·40	13·00	9·00	3·40	1,750	15·32	14·52	12·12	8·11	2·51
1,900	18·05	17·25	14·85	10·85	5·85	1,850	17·12	16·32	13·92	9·92	4·31
2,000	20·01	19·21	16·80	12·80	7·20	1,950	19·02	18·22	15·82	11·81	6·21

APPENDIX

ON THE LINE OF COLLIMATION AND VIRTUAL LINE OF SIGHT, AND THE FAILURE OF "GRAVATT'S METHOD" TO DETECT A DISCREPANCY BETWEEN THEM.

In *Plate* XXII, these two lines are very clearly distinguished.

The **line of collimation,** being defined as the direction of the ray of light which passes through the optical centre of the object glass and the intersection of the cross wires or middle vertical thread midway between the two horizontal threads, as the case may be (*vide* p. 74) is shown by rays q_1 OQ_1, q_2 OQ_2, q_3 OQ_3, &c.

The **virtual line of sight,** being the 'locus of points observed,' is shown by the line dFQ_1 Q_2Q_3.

On reference to Chapter IV. of this Manual, it will be seen that the object of the first permanent adjustment of optical instruments whose telescopes lie loosely in Ys, is to make the line of collimation coincide with the axis of the interior cylindrical surface of the Ys. so that no error may occur in observation owing to the telescope having, by accident, turned in the Ys. If perfectly constructed, the Y axis of these instruments is made to coincide with the optical axis of the system of lenses, so that the *line of collimation and the virtual line of sight* would, under these circumstances, likewise coincide.

In the case of instruments not so mounted, the telescopes of which are not liable to turn in Ys, it is in no way necessary for accurate observation (as will subsequently appear) that these two lines should coincide, all that is necessary being to set the upper level to indicate the horizontality of the virtual line of sight, at the same time that the vertical arc, if there be one, reads zero.

The exact coincidence, however, of these two lines was formerly held to be absolutely necessary for accurate observation, and the easy detection of a discrepancy between them was claimed for Gravatt's method of adjustment in collimation. It will be shown in the following pages, which are selected from Papers XXI and XLVII, Vol. I., Second Series, of the "Professional Papers on Indian Engineering," by Lieut.-Colonel A Cunningham, R.E., that this method is practically a failure for the object in view.

The criticism of the method will be preceded by some remarks on the optical principles involved and the functions fulfilled by the parts of a

telescope, and during the investigation the curve of the locus of points observed will be investigated.

The references throughout are to Parkinson's "Treatise on Optics," (2nd Edition of 1866).

Preliminary remarks—In almost all surveying and astronomical instruments the telescopes are technically "astronomical telescopes" *i.e.*, they consist of a compound achromatic object glass, with a Ramsden's compound eye-piece placed at a distance apart of about the sum of their focal lengths, and with axes nearly coincident (Arts. 204 and 239).

From every *point* of an object viewed a cone of rays falls on the object glass; the objects to be observed in these telescopes are in practice so distant that each of these cones is merely a very small pencil of rays: the axis of this small cone or pencil for any particular *point* of the object viewed is the direction (external to the telescope) in which that point is viewed: it seems natural to call this line "the line of sight of the telescope."

For surveying, *i.e.*, for angular measurement, and for levelling, the directions of the axes of the pencils (incident on the object glass) by which points are viewed are the only lines of importance. For angular measurement *the angles required to be measured* are the projections on the planes of the graduated plates of the angles contained between the several axes of those pencils, whereas *the angles that are actually measured*, after eliminating errors of graduation and bad centering, are (by the construction of the instruments) the projections on those planes of the angular motion of the axis of the object glass of the telescope between the several observations.

The sole function of the object glass is to produce a nearly flat image or picture of the object viewed in a plane perpendicular to its own axis (Art. 204).

In all cases of oblique refraction through a lens such as the object-glass is, the image of a point is not a single point, but a series of overlapping "circles of confusion" (Arts. 147 and 65); the "circle of *least* confusion" for each point is taken for *the* image of the point (Art. 65).

The image of any point viewed as Q_1 (*Fig.* 1 Plate XVII) not lying on the axis of the lens, *i.e.*, the "focus conjugate to" the point Q_1, being the focus of a small "oblique centrical pencil" (Art. 115) lies on the line joining Q to a certain point O called the "centre" (Art. 109) of the lens, and is the centre of the "circle of least confusion" corresponding to Q_1, *viz.* q_1 *i.e.*

q_1 is *the* image of Q_1 and $q_1 OQ_1$ is the direction of the visual ray : this is evidently what has been called above " the line of sight of the telescope."

The pencil diverging from Q therefore converges to q : the human eye is, however, fitted to see objects only by rays which are very nearly parallel (and not convergent).

To enable the image to be seen, therefore, the rays converging on q must be rendered parallel : this is arranged by viewing through a Ramsden's eye-piece E (Art. 204 and 236), which is set by the act of focussing in the position in which the image is most distinct, which occurs when the rays of the pencil corresponding to each point (q) viewed leave it nearly parallel, in which case the principal focus of the eye-piece is very near the plane of the general image formed by the object-glass.

It is to be particularly noticed that the sole function of the eye-piece is to view and magnify the image already formed by the object-glass, and it, therefore, has no influence on the direction of the axes of external pencils (or lines of sight of the telescope).

On looking through such a telescope as has been described, one commands a considerable field of view, but for all purposes of measurement it is necessary to have some means of confining one's attention to some definite line of sight, so arranged that the angles actually measured may be the same as those which are required to be measured, as has been already fully explained. With this view a set of fine hairs crossing one another is placed in the telescope tube on an open diaphragm DD, or is scratched on a glass one, whose plane is nearly perpendicular to the axis of the object-glass.

The act of focussing must be so managed as to make both the cross hairs and image appear distinct, and also relatively fixed, no matter to what part of the eye-piece the observer applies his eye (that is so that the hairs and image may have no apparent parallax).

The "centre of position" of the set of hairs in an astronomical instrument, the (single) intersection of the hairs in a theodolite, and the middle of the horizontal hair in a level, are taken for the points of reference in the field of view.

After adjusting for distinct vision and parallax, the telescope is shifted by the tangent screws so that the intersection of the cross wires may apparently cover or " bisect " the particular *point* of the object which is to be observed.

Since the cross hairs and picture are seen without apparent parallax, they are in one plane, and since the intersection of the hairs seems to cover or " bisect" the point Q of the object viewed (*Fig.* 1, *plate* XVII),

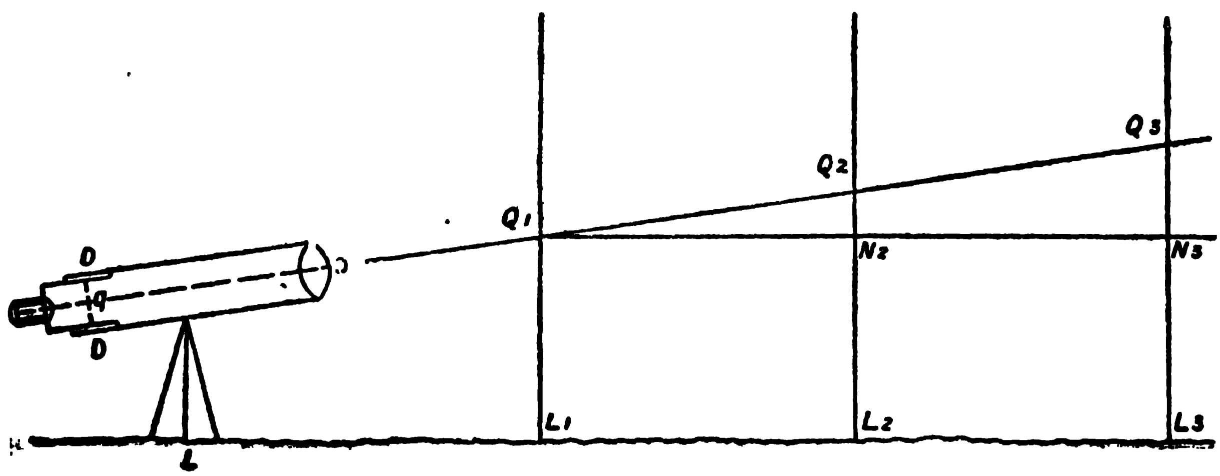
it follows that their intersection has been brought into the line QO, and into the very point q above described as *the* image of Q. Hence the line joining this intersection of the hairs to the " centre" of the object-glass, which is a line appertaining to the telescope, and has been called the " line of collimation " now coincides with the "line of sight of the telescope," which is a line external to the telescope.

It will be advisable first to explain " Gravatt's Method " of adjustment in detail, then to investigate theoretically the possibility of its application within practical limits; it may be added that very careful experiments were made by Col. Cunningham expressly to test his conclusions. A full description will be found in paper No. XLVII., Vol. I., of the "Professional Papers on Indian Engineering."

" Gravatt's method " of adjustment in altitude of the line of collimation..— This method is thus performed :

Three levelling staves $Q_1Q_2Q_3$ are ranged in a straight line Q_1Q_2 and held as upright as possible : the distance Q_1Q_2 must be within the range of good definition of the telescope to be used (*see Fig.* 128).

Fig. 128.



The difference of the level of the feet $L_1L_2L_3$ of the staves are found as accurately as possible; it is admitted that this can be accurately done with a level, even though not in adjustment, by simply placing the level *midway between* staves Q_1Q_2, and also *midway between* Q_2Q_3, and bringing the bubble to the centre of its run on each occasion of making a reading.

The level, which it is wished to adjust, is then set up on the line $Q_1Q_2Q_3$ as at L, far enough from Q_1 to admit of clearly reading that staff. The telescope is directed in the plane of the staves $Q_1Q_2Q_3$, and the bubble brought to some definite position, which can be easily recognised (it is not necessary that it should be in the centre of its run). The three staves $Q_1Q_2Q_3$ are now read in succession; it is essential that the telescope

remain quite steady throughout this period; as the staves are in the same vertical plane as the telescope, there is no necessity to touch the telescope except to focus it; any departure of the bubble from its original position must be corrected by its foot-screws.

Let $Q_1Q_2Q_3$ be the points viewed and read on the three staves in succession.

Now, applying the differences of level of the feet L_1, L_2, L_3 of the staves already found with their proper algebraic signs to the height L_1Q_1 (= the reading on the first staff), the heights L_2N_2, L_3N_3 at which a level line $Q_1N_2N_3$, through Q_1 cuts the staves Q_2Q_3 can be ascertained.

Taking the differences of the heights of the level line, and of the heights of Q_2, Q_3 above L_2, L_3 respectively, the differences of level of the points $Q_1Q_2Q_3$ can be obtained thus:

$$Q_2N_2 = Q_2L_2 \backsim N_2L_2, \text{ and } Q_3N_3 = Q_3L_3 \backsim N_3L_3.$$

Now if $Q_1Q_2Q_3$ lie *on any straight line whatever*, the following proportion would evidently obtain $Q_2N_2 : Q_3N_3 :: Q_1N_2 : Q_1N_3$.

Also, if there be "no error in the line of collimation," *i.e.*, if the middle of the horizontal hair q, *Fig.* 2, traverse the object-glass axis O, it is easily seen that the "line of collimation" qO always coincides with the object-glass axis, and that therefore the points $Q_1Q_2Q_3$ (which necessarily lie on the "line of collimation" qO) must lie *on that straight line*, and on trying "Gravatt's method" the proportion $Q_2N_2 : Q_3N_3 :: Q_1N_2 : Q_1N_3$ will of course be found to hold.

But, if there be an error in altitude in the "line of collimation," *i.e.*, if the middle of the horizontal hair be in the position q, *see Fig.* 1, Plate XVII (not on the object-glass axis CO), its middle point will traverse the line $q_1q_2q_3$ parallel to the object-glass axis in the act of focussing for obtaining distinct vision of the staves Q_1, Q_2, Q_3 which are *at different distances* from the level.

The "line of collimation" qOQ will no longer be a fixed line, but will have the three positions q_1OQ_1, q_2OQ_2, q_3OQ_3, on viewing the three staves Q_1,Q_2,Q_3, so that the three points Q_1,Q_2,Q_3 will not range on the object-glass axis CO, and it *might be supposed* that the ratio $Q_2N_2 : Q_3N_3 :: Q_1N_2 : Q_1N_3$ would no longer hold.

It *has been actually supposed hitherto* that unless the points viewed Q_1,Q_2,Q_3 lay *actually on the object-glass axis* CO produced, this proportion would not hold, and that, consequently, if actual trial, on the proportion were found to hold good, it *was supposed* to be a proof that the "line of collimation" was correct, and further, that if on actual trial it were found that this proportion did not hold, it *was supposed* that the difference

of the actual length Q_3N_3 from that required by the proportion, *viz.*, $Q_2N_2 . \frac{Q_1N_3}{Q_1N_2}$ would be *a measure of the error in altitude* of the horizontal hair.

Let it then be understood that it is this difference of length, *viz.*, $Q_3N_3 \backsim Q_2N_2 . \frac{Q_1N_3}{Q_1N_2}$, that is to say, the amount of departure of one of the points Q_3 from the straight line Q_1Q_2 joining the other two, which "Gravatt's method" proposes to find (by observation), and to consider a measure of the error in altitude of the horizontal hair.

Investigation of the curve which is the locus of Q.—The form of the curve on which all the points viewed, (*i.e.*, covered by the middle of the horizontal cross-hair) lie, will now be investigated, and it will be shown that it is so flat a curve, that *the departure* of any point on it from a certain stright line (required to be measured by Gravatt's method) is so small *within the limits practically obtainable*, that it falls within the limit of the errors of observation, *i.e.*, *cannot be measured.*

It will be assumed as follows :—

(1) In spirit levels, the focussing screw moves either the object-glass only, or else the diaphragm and eye-piece together: the instrument should be so constructed by the maker, that (*see Fig.* 1 Plate XVII) in the former case, the object-glass "centre" O, (Parkinson, Art. 109), moves along its axis CO, and in the latter case, the middle of the horizontal hair q should move either along that axis CO or on a straight line $q_1q_2q_3$ parallel to it.

(2) The "line of collimation" is the line qO joining the middle of the horizontal hair q to the "centre" O of the object-class, and is aligned with *the point* Q, chosen for observation, (*see figs.* 1 and 2 Plate XVII).

(3) The centre of "the circle of least confusion," (Parkinson, Art. 64), q corresponding to the *point* viewed Q is *the* image of that point (Art. 65).

N.B.—It might be supposed that the achromatic object-glass being (in common parlance) corrected for spherical aberration, there would be no "circles of confusion," (these being due to spherical aberration), but the glass is in fact corrected for spherical aberration *only for parallel rays directly incident*, (Art. 223). Now as the use of "Gravatt's method" necessitates reading a staff as close to the object-class as a distinct vision wil ladmit, the incident rays are not parallel, but *divergent*, and are also not directly incident, but *oblique* whenever the horizontal hair is out of its

proper position (the very case in hand), so that "circles of confusion" exist.

(4) It will be found *by actual trial*, that *the greatest error* likely to be made in fixing a hair on the diaphragm, and inserting the diaphragm in the telescope entails an error of deviation of the horizontal hair, qm in figure, from the object-glass axis CO, (the amount of deviation will be denoted by k) of *less than* $\frac{1}{10}$ inch. $\therefore$ $qm = k < \cdot 1$ inch.*

(5) Again, the smallest levels usually employed have object-glasses of about 10 inches focal length, *i.e.*, the distance of the inner principal focus of the object-glass from its posterior surface (hereafter denoted by f) is *never less than* 10 inches. $\therefore$ f not < 10 inches.

(6) Again, if ϕ be the angle of obliquity QOF (*Fig.* 1, Plate XVII) of the axis of incident rays QO, *i.e.*, inclination of their axis to the object-glass axis CO, then (as is also easily seen by trial) the distance from the horizontal hair q to the object glass is least for distant objects, and increases as the object viewed approaches. It follows that f (being the distance between the hair and object-glass for infinitely distant objects) is the *least* distance of q from the object-glass.

$\therefore$ $\tan \phi = \tan \text{QOF} = \tan q\text{CO} = k \div \text{O}m < k \div f$, for $\text{O}m > f$. Also $k < \cdot 1$ inch, and f not < 10 inches.

$$\therefore\ k \div f < \cdot 1 \div 10,\ i.e., < \cdot 01.$$

But for small angles $\phi < \tan \phi$, which is $< k \div f$, which $< \cdot 01$.

$$\therefore\ \phi < \cdot 01\ \textit{à fortiori}.$$

This result is very important as it is entirely on account of the *smallness of the obliquity* ϕ that "Gravatt's method" practically fails.

First approximation the locus of Q.—It is shown (Parkinson, Arts. 112 and 113) on the approximate assumptions.

(1) That the object-glass is indefinitely thin.

(2) That the obliquity ϕ is so small that its square may be neglected, that $\frac{1}{\text{O}q} = \frac{1}{\text{OQ}} + \frac{1}{-f}$, f being considered negative (Art. 102), because the object-glass is to be considered a convex lens (Art. 204).

Second approximation to the locus of Q.—It is shown (Parkinson, Art. 113 Cor. 4) on the assumptions.

(1) That the object-glass is indefinitely thin.

(2. That the obliquity ϕ is so small that its fourth power may be neglected, that $\frac{1}{\text{O}q} = \frac{1}{\text{OQ}} + \frac{1}{-f} + \left(1 + \frac{1}{\mu}\right)\frac{\phi^2}{-2f}$.

Comparison of approximations.—

Let $\text{OQ} = r$, $\text{QM} = y$, $\text{OM} = x$,

* In the figure qm has been purposely exaggerated to avoid confusion

$\therefore Oq = \frac{kr}{y}$ from the similar triangles QOM, qOm.*

1st approximation $y = k - \frac{kr}{f}$.

2nd " $y = k - \frac{kr}{f} - \left(1 + \frac{1}{\mu}\right) \frac{\Phi^2}{2} \cdot \frac{kr}{f}$

Let δy be the difference of the ordinate y for *the same radius vectorr*, then $\delta y = \left(1 + \frac{1}{\mu}\right) \frac{\Phi^2}{2} \cdot \frac{k}{f} \cdot r$ (being difference of above approximations).

It was shown, para. (6), that $\Phi < \cdot 01$ and $\frac{k}{f} < \cdot 01$.

Also μ varies from 1·67 for flint glass, to 1·5 for crown glass (Parkin son, Art. 162).

Assuming $\mu = 1{\cdot}6$, $\delta y < \left(1 + \frac{1}{1{\cdot}6}\right) \frac{(\cdot 01)^3}{2} \cdot r$

$$< \frac{1{\cdot}625}{2} \times \cdot 000001 \times r, \textit{ i.e.}, < \cdot 000008 \times r.$$

Now with a 10-inch level, 300 feet is about the utmost limit of accurate reading.

$\therefore$ the greatest value of $\delta y < \cdot 000008 \times 300$ feet, an inappreciably small quantity.

With large levels the limit of distance r increases say to 500 feet, but the small fraction $\Phi^2 \frac{k}{f}$ decreases much more rapidly.

Thus it has been shown that within the limit of distance attainable in practice, the curve denoted by the second approximation differs from that denoted by the first approximation, by an inappreciable quantity, *even when the error* in position of the horizontal hair is *at its greatest*. It is obviously unnecessary to try any closer approximations as far as the powers of θ are concerned.

It should be noticed that these results have been obtained on the approximate hypothesis that the object-glass is indefinitely thin; it is not thought necessary to introduce the thickness of the object-glass into the investigation, as it greatly complicates it without materially affecting the above general conclusion.

It may now be shown that the locus of Q is a line differing inappreciably within the limits of practice from a straight line.

For $x = r \cos \Phi = r\left(1 - \frac{\Phi^2}{1\cdot 2} + \frac{\Phi^4}{1\cdot 2\cdot 3\cdot 4} - \&c.\right) = r$ nearly, *i.e.*, on the same assumption as that by which the first approximation to the locus

* *N.B.*—Positive ordinates being measured downwards, the sign of k, *i. e.* $mq = Od$ is to be considered *inherently* negative throughout what follows.

Elimination of errors produced by an error in the line of collimation.—

1. In measuring angles, as with theodolites and altazimuths, the *readings* corresponding to objects situated at *different* distances from the observer are differently affected, so that the resulting angles (being the differences of these readings) are incorrect.

The error due to this cause may, however, be wholly eliminated by the simple plan of observing *every* point twice (or any even number of times with the telescope in reversed positions: there will then be two sets of errors *equal and opposite* for each point, (although differing for points at different distances), which will be eliminated in taking the mean.

2. In levelling, the error due to this cause may also be wholly eliminated from the general result by the simple plan of always placing the level at equal distances from the furthest back-staff and furthest fore-staff. The error in *reading* on these two staves will then be equal, so that the resulting difference of level (being the difference of the readings) will be correct. The readings on intermediate staves will be differently affected according to their distance from the instrument, so that the resulting reduced levels at all the intermediate staves will be affected by this error, but these errors will be all small and not *cumulative* (the difference of level having been correctly obtained between the furthest staves). Small errors in levelling when not cumulative are of no importance.

N.B.—Observing as above indicated (paras. 1 and 2) has many other advantages in eliminating errors due to other causes, which it is not within the scope of this paper to enumerate.

INDEX.

A.

F.

G.

H.

I.

L.

M.

N.

O.